The Effects of Sandbar Formation and Inflows on Aquatic Habitat and Fish Utilization in Pescadero, San Gregorio, Waddell and Pomponio Creek Estuary/Lagoon Systems, 1985-1989

Jerry J. Smith

Department of Biological Sciences
San Jose State University
San Jose, CA 95192

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ABSTRACT

The fish habitat quality of the small lagoon/estuaries at Pescadero, San Gregorio and Waddell creeks was generally good, but limited in extent, when the stream mouths were open to full tidal mixing in winter and early spring. In late spring, summer and fall, habitat quality depended primarily upon the timing of sandbar formation and breaching and upon the quantity and quality of freshwater inflows to the lagoons after sandbar formation. Adequate inflows to these shallow lagoons after bar formation resulted in rapid conversion of the lagoons to unstratified fresh water, relatively cool water temperatures, high dissolved oxygen levels and high invertebrate abundance. Low inflows to the lagoons, due to late sandbar formation, drought or upstream (human) diversions, resulted in delay or failure of salinity destratification. Saline, stratified lagoons acted as solar collectors and had higher water temperatures, especially within the more saline bottom waters. Stratified lagoons also often had low bottom dissolved oxygen levels and reduced invertebrates.

Summer or early fall natural or artificial sandbar breaching was usually rapidly followed by sandbar re-formation, resulting in stratified, saline, warm and unproductive lagoons. However, in the summer of 1989 the sandbar at Pescadero Lagoon remained open for several months after artificial sandbar breaching. Although the upstream portions of the estuary were shallow, stratified and warm, the well-mixed main embayment was cool and well-oxygenated.

Fish Diversity increases w/ size

Fish populations utilizing the lagoons consisted of freshwater, estuarine and saltwater species. The number of species increased with lagoon size. The highest diversity occurred at Pescadero Lagoon in early summer of 1986, when many juvenile saltwater fishes were present in the open lagoon. After lagoon conversion towards freshwater conditions, following sandbar closure, many saltwater species declined or disappeared. Many species also declined or disappeared in the warm, saline, unproductive lagoons associated with the drought years.

Juvenile steelhead survival and growth was excellent when the lagoons were open to full tidal mixing and when the closed lagoons were converted to fresh water. Growth was poor during long, stratified transition periods between sandbar closure and conversion of the lagoons to fresh water. Survival was poor during periods of prolonged warm, stratified conditions. The high numbers and/or large sizes of steelhead reared in the lagoons during years of freshwater conversion demonstrate that these lagoons can potentially contribute the majority of steelhead smolts produced in these small coastal watersheds.

Managing these lagoons for production of juvenile steelhead requires: 1) prevention of artificial summer sandbar breaching; and 2) insuring sufficient inflows after sandbar formation to rapidly convert stratified, saline lagoons to fresh water.

INTRODUCTION

The annual summer drought in California results in sharp declines in streamflows in coastal streams. For smaller streams, declining streamflow and summer beach development result in development of a sandbar which dams the stream mouth to produce a lagoon. These lagoons may provide warm, deep-water areas for swimming and boating and habitat for fish and wildlife. The raised water levels behind the sandbar can also flood adjacent lands, producing valuable wetlands and/or threatening agricultural or urban developments. Despite recent interest in wetlands and estuaries, relatively few studies have been done on California central coast lagoons, although they were long ago shown to be important for steelhead (Oncoryhnchus mykiss) and salmon (O. kisutch) (Shapovalov and Taft 1954). Lagoons and their associated wetlands have been actively managed by diversion of inflow waters for agricultural and municipal uses, diking of surrounding land, and artificial breaching of the sandbar for flood, odor, and insect control. This report summarizes the results of studies undertaken for the California Department of Parks and Recreation to determine habitat dynamics and fish utilization in four small coastal lagoons. The goals of the studies were: A) to provide information to guide the restoration and management of wetlands and the estuary/lagoon at Pescadero Marsh Natural Preserve (NP); and B) to provide information on sandbar management and lagoon inflows necessary to maintain aquatic habitat in the face of upstream diversions and drought conditions.

STUDY AREAS AND METHODS

Although the primary management interest was in the lagoon at Pescadero Marsh NP in San Mateo County, two smaller San Mateo County and one Santa Cruz County estuary/lagoon systems were also investigated. Pescadero lagoon receives the waters of Pescadero and Butano creeks on a broad lowland; the summer water levels can inundate over 300 acres of wetlands, including partially leveed former farmlands, within Pescadero Marsh NP. San Gregorio Creek lagoon primarily occupies a large incised channel. High water levels spread over the sandy beach area, but upstream of Highway 1 they seldom flood much land outside of the main stream channel. Waddell Creek lagoon generally has an even smaller embayment, and is primarily a narrow, drowned stream channel. Pomponio Creek lagoon is at the mouth of a very small stream with negligible summer flow; the embayment behind the summer sand bar usually contains mostly saline water impounded at the time of sandbar formation and from wave overtopping of the bar.

Water Quality

Temperature, salinity, and dissolved oxygen profiles were determined approximately monthly at an average of 16 sites (see Appendices for site locations, dates and data) in Pescadero Creek estuary/lagoon in spring, summer, and fall of 1985 and 1986. Limited summer and fall water quality sampling also took place in 1984. In 1987, 1988, and 1989 temperature, salinity, and dissolved oxygen profiles were determined approximately monthly in spring, summer, and fall, but on most dates sampling was limited to the Highway 1 bridge site only.

In Pomponio, San Gregorio, and Waddell creek lagoons temperature, salinity, and oxygen profiles were determined three times at 3 - 9 sites in 1985 and four times in 1986. Limited additional water quality sampling at the Highway 1 bridges was performed numerous times in 1985 and 1986. In 1987, 1988, and 1989 water quality profiles were determined approximately monthly in spring, summer and fall at Highway 1 bridge sites at San Gregorio and Waddell creek lagoons.

USGS stream gages are located on Pescadero and San Gregorio creeks, but give only an approximation of lagoon inflows. The Pescadero Creek gage is 5.3 miles upstream of the mouth, and there are numerous diversions between the gage and the lagoon. Butano Creek, a major ungaged tributary, enters Pescadero Creek at the lagoon/estuary. The San Gregorio Creek gage is 1.4 miles upstream of the mouth, and several agricultural diversions exist between the gage and the lagoon. Waddell Creek is ungaged, but some streamflow data exist for the bypass at the diversion immediately upstream of the lagoon.

Invertebrates

Invertebrate populations at seven sites in Pescadero lagoon were sampled with dredge, sled, and plankton net six times in 1986 and six times over the 1987 - 1989 drought period. Ongoing invertebrate studies are the subject of a master's thesis project by Mark Robinson (Department of Biological Sciences, San Jose State University).

Fish Populations

Fish populations in Pescadero lagoon were sampled by beach seine six times each in 1985 and 1986 to determine species, ages and size classes present. They were sampled twice by seine in 1984. Gill net sampling was also extensively used in early summer 1985, but was used only sparingly for the remainder of 1985 and in 1986 because of substantial size and species capture selectivity. Later gill net sampling was used primarily to capture starry flounder (Platichthys stellatus), which were seldom captured by seine. Fish populations in the lagoon were sampled by beach seine twice in 1987, twice in 1988, and twice in 1989. In addition, steelhead populations in Pescadero Creek were sampled by backpack electroshocker in the summer and fall of 1986 and the fall of 1987, 1988, and 1989.

In Waddell and San Gregorio creek lagoons fish populations were sampled by beach seine three times in 1985 and four times in 1986. San Gregorio Creek lagoon was sampled once in fall 1988, and Waddell Creek lagoon was sampled twice in spring and once in fall 1988. Pomponio Creek lagoon was sampled three times in 1985 and once in 1986.

Relative Importance of Lagoons for Steelhead Rearing

Scales taken from 27 adult steelhead caught by anglers or in our sampling at Pescadero Creek lagoon from 1985 to 1989 were used to determine the proportion of adult steelhead which reared in the lagoon as compared to rearing in the remainder of the watershed. Back-calculated sizes at annuli and at entrance to the ocean and seasonal growth rate patterns were used to determine probable rearing sites with the watershed. Scales taken from fish reared in the lagoon and at stream sites were used as references for the rearing site determinations.

RESULTS AND DISCUSSION

Water Quality and Habitat Conditions

Habitat conditions and water quality in the lagoons were a result of interaction of a variety of factors, including shape and size of the stream channel, timing of bar formation, substrate dynamics and types, weather, upstream habitat and land use, and flow-related effects upon lagoon depth, salinities, temperatures, and dissolved oxygen. The interactions and impacts of the major habitat factors are summarized below.

Bar Formation and Destruction

Bar formation and destruction is dependent upon a number of variables, including: wave dynamics, sand abundance and distribution, coastline shape, streamflow, and channel width and volume.

Wave Dynamics. High energy winter storm waves (high, steep) erode beach sand and remove the sandbar, and high stream runoff can widen and deepen the mouth of the lagoon. In 1985 storms were weak and few, and much of the beach near all four streams remained intact. Spring and summer low-energy waves rebuilt the beach and sandbars early. At Pescadero Creek the stream mouth had been blocked by a sandbar by early May (see Table 1 for dates of sandbar closure). In 1987 the drought conditions and lack of late winter storms resulted in bar formation in late March at Pescadero, and mid to late May at San Gregorio and Waddell. In 1988 sandbars were closed by late March or early April at Pescadero, San Gregorio and Waddell lagoons, but were breached during a late April (22-24th) storm; sandbars re-formed by mid to late May.

In February of 1986 intense storms removed much of the sand from the beaches at all four streams. The beach at Pescadero Creek was gradually rebuilt, and the sandbar was not fully formed until mid July. Because of the estuary's large size, tidal action on the winter-eroded beach was sufficient to keep the mouth open long after streamflow had been sharply reduced by summer drought and water diversions. At San Gregorio Creek the 1986 winter storms removed much of the beach, but also shifted the stream mouth to the north. Since bar formation usually starts at the north end of the beach, the sandbar at San Gregorio actually closed off earlier in 1986 than in 1985.

Once formed, the sandbars normally persist until eroded by winter storms or until they are artificially breached. The buildup of large lagoon water volumes and even substantial tidal overwash are insufficient to breach the summer sandbar, unless accompanied by steep, erosive waves. In fact, tidal overwash usually strengthens the bar by depositing sand on the crest and inboard side, raising and widening the bar. Artificial breaches at Pescadero Creek in October 1985, October and December 1986 (Figures 2 and 6), and at Waddell and San Gregorio (Figure 22) creeks in the summer of 1986 were quickly plugged by wave-deposited sand. Even though the open lagoons were quickly closed, substantial harm was done to lagoon resources.

In summer 1986 very high waves from a tropical storm were probably responsible for temporary sandbar breaches at San Gregorio and Waddell creek lagoons.

Sand Abundance and Distribution. The general pattern of wave dynamics and sandbar formation and destruction may hold in most years, but may be altered by sand distribution in drought years. In 1989 sandbars formed late at both San Gregorio and Waddell creek lagoons, despite the relatively mild winter of 1988-89.

The slow closure of the sandbars was especially suprising, as the beaches at the stream mouths remained unusually wide all winter. It appears that during periods of drought and weak wave action much of the sand in the littoral cell may become stockpiled in the enlarged beach. This may leave little sand to move with summer waves and to close off the stream mouth.

It is also possible that as summer progresses more sand is stored in the beach and progressively less sand movement occurs with regular wave action. In 1989, Pescadero Creek lagoon remained open for most of the summer after artificial sandbar breaching. The bar re-formed in September, however, after a mild storm. The storm may have eroded some of the beach sand and made it "available" to plug the stream mouth.

Coastline Shape. Prevailing summer wind and waves are from the northwest, resulting in southward littoral drift of sand along the beaches. Therefore, the length of the beach and the position of the stream mouth in relation to bluffs on the north or south boundaries of the beach are major factors in bar formation. Waves and wind accompanying major storms are usually from the southwest, so coastline shape similarly has a major effect on bar persistence. The position and design of the Highway 1 bridges may also influence beach and bar dynamics by constraining the position of the stream mouth.

At Pescadero Creek the mouth is adjacent to the projecting headlands at the southern end of the beach. In addition, the Highway 1 bridge is within 180 m of the ocean, restricting lateral movement of the mouth. Southward sand movement quickly accumulates and is trapped by the hook-like northward projection of the headlands. This fact was recognized years ago and a tunnel was drilled through the cliff to retard the closing of the lagoon. Despite the tunnel, the sand bar at Pescadero Creek normally will completely close about a month or more before the bars at San Gregorio or Waddell creeks (Table 1). Because of the location, orientation, and narrowness of the mouth, the complete closure of the bar is often very quick and unpredictable. In 1986 the bar was still open in mid July, with tidal flows of over one hundred cfs streaming in and out; 3 days later only the tunnel was open, and the tunnel was fully closed within a week! The headlands also protect the bar from storm waves from the southwest. In 1986 unusual summer storm waves apparently eroded and temporarily breached the bars at San Gregorio and Waddell Creeks, but the Pescadero bar was unaffected. Similarly, small storms in November and December 1986 breached the bars at San Gregorio and Waddell creeks, but actually increased the volume of sand in the Pescadero bar.

At San Gregorio, Waddell, and Pomponio creeks there are no protective headlands, and the southward summer sand movement tends to displace the stream mouths southward and to very gradually close them off completely. At San Gregorio and Waddell creeks the long, meandering outlets may remain open for one to two months after the sandbar has substantially formed, delaying the rise in lagoon water level and potentially delaying the conversion of the lagoon to freshwater. Under partially closed conditions, occasional tidal inflows renew the bottom salt water layer, but outflow is primarily fresher surface water.

At San Gregorio Creek the Highway 1 bridge is farther back from the ocean, and the location and shape of the lagoon vary from year to year. In 1986 storm waves eroded the beach and displaced the stream mouth against the northern bluff, resulting in a deeper lagoon than usual and also hindering public access to the beach.

Streamflow and Tidal flow. For these relatively small streams, streamflow is a not the dominant factor in sandbar formation and destruction. Streamflow at the time of bar formation (Table 1) can vary substantially from year to year, and in most cases bar formation occurs long after spring streamflows are reduced below levels sufficient to prevent bar formation. At Pescadero Creek, because of the mouth configuration, partial sandbar closure is quickly followed by full closure, even at relatively high streamflows (Table 1). However, at San Gregorio and Waddell creeks streamflow may be an important factor in maintaining the outlet channel through the wide sandbars and producing a relatively long transitional period to full sandbar closure.

Tidal flow usually substantially exceeds streamflow at the time of sandbar formation, and is probably more important than streamflow in retarding sandbar formation. During bar formation in late spring and summer, tidal flow might exceed 50 cfs at Pescadero or San Gregorio creeks, while freshwater inflows to the lagoons might be less than 5 cfs. At San Gregorio and Waddell creeks the gradual widening of the partially-formed sandbar reduces the amount and frequency of outlet scouring, allowing the sandbar to fully close.

Once the bar is fully formed there is still sufficient seepage through the bar to prevent its being overtopped and eroded by moderate inflows (5 - 15 or more cfs, depending upon bar length and width and lagoon depth). In the winter storms that caused breaching of the sandbars at the lagoons in 1985 and 1986, the storm waves accompanying the rain eroded and breached the bars before any significant flood flows reached the lagoons. High streamflow between storms at Waddell Creek did appear to produce a cycle of lagoon filling and breaching in late fall and winter 1986. In October 1989 increased streamflow after the Loma Prieta earthquake and an early storm partially opened the sandbar at Waddell Creek lagoon, producing a long meandering outlet that lasted well into winter; normally such heavy streamflow would have been accompanied by storm waves, which would have eroded the sandbar. Similarly, substantially increased streamflow on Pescadero Creek followed the earthquake, but the sandbar remained because of the absence of erosive wave action.

Channel Width and Volume. At Pescadero Creek over a hundred acres are potentially open to full tidal exchange, much of it in the very large embayment immediately upstream of Highway 1. During the period of sandbar formation, the large volume of tidal exchange results in scour at the mouth and retards its blockage with sand. The Highway 1 bridge, which is very close to the ocean, concentrates outflowing tides and increases their scouring ability.

In 1989 artificial breaching of the Pescadero Creek lagoon sandbar to facilitate work on the new Highway 1 bridge maintained an open lagoon for much of the summer. Apparently the deep sandbar cut caused by artificial breaching, together with the very large tidal prism, resulted in the need for only a few artificial breaches to keep the lagoon open for summer and fall. In addition, inflowing tidal water produced a "reverse delta," with a fan of tidal-deposited sand extending over 50 m upstream of the bridge. The new Highway 1 bridge is slightly closer to the ocean, but has fewer, smaller pillars, and may modify tidal scour and the timing of sandbar formation at Pescadero Creek.

At San Gregorio and Waddell creeks, most of the lagoon volume is normally in the narrow, incised stream channel upstream of the Highway 1 bridges. The shape of those lagoons normally greatly reduces the upstream extent of tidal mixing and amount of tidal exchange and scouring at the mouth. In 1986 the San Gregorio Creek mouth moved north against the cliff, rather than directly opposite the highway bridge, creating a much larger embayment downstream of the bridge. Tidal mixing in the open lagoon was increased by the larger tidal prism, but the effect was still largely confined to the embayment downstream of the bridge. If the present benchlands on the north side of San Gregorio Creek, upstream of the bridge, were excavated and opened to the creek to create wetland habitat, tidal mixing in the estuary and scouring at the mouth might be somewhat increased.

Lagoon Depth

Lagoon depth is a function of fill and scour in the stream channel and adjacent wetlands and of the interaction of streamflow, bar formation, seepage, overwash, and channel volume.

Scour and Fill. Although local residents report that Pescadero, San Gregorio, and Waddell lagoons were originally in excess of 5 m deep, those conditions reflected the drowning of river mouths cut at lower ocean levels (during the ice ages). Recent watershed erosion has filled the lagoon basins, so that now all three are less than 1 meter deep when at low tide and open to full tidal action. Pomponio is often less than 0.25 meter deep during winter.

Present rates of sediment input to the lagoons offer little hope of improvement in basin depth, but also did not appear to reduce the depth during 1985 or 1986. At Pescadero Marsh NP the February 1986 storms resulted in sustained flood flows for nearly 2 weeks. Pescadero Creek, upstream of the main estuarine embayment (sites 18-24), showed substantial movement of sediment, with some alteration in pool/riffle sequences, scour on the outside of bends, and deposition on the inside of the bends. The average depth of that portion of the channel, however, did not appear to be altered, although substantial amounts of gravel were added to the substrate. On Butano Creek, which joins Pescadero Creek immediately upstream from the main embayment, much fine sediment was added to the sides of the channel at sites 8 - 11. Maximum channel depth was not reduced, but the channel bottom changed from a relatively uniform to a v-shaped cross-section. In the main embayment no significant change in channel depth appeared to occur, even at the bridge where flood waters might be expected to scour. The bedrock sill at the restricted mouth of the stream appears to prevent significant scour below the present channel bottom.

At Pescadero, San Gregorio, and Waddell lagoons the deepest water is near the Highway 1 bridges, where local scour is increased around the pilings and abutments. Prior to the drought additional deep areas were present on the outside of channel bends within each lagoon.

During the drought winters of 1986-87, 1987-88 and 1988-89 substantial deposition apparently occurred in Pescadero, San Gregorio, and Waddell creek lagoons because the mild winter storms were able to move sediment to the lagoons, but flows were too weak and too short in duration to move the sediment through the lagoons. At Scott Creek, immediately south of Waddell Creek, the lagoon was nearly filled by aggraded sand and gravels in spring of 1988. Dense growths of pondweed (Potamogeton foliosus) in the lagoons in the summers of 1987 - 1989 were not completely scoured by winter flows and appeared progressively earlier and in greater abundance each summer. Winter sediment deposition was especially great within the pondweed. At Waddell Creek lagoon sedimentation upstream of the Highway 1 bridge has reduced lagoon depth there by approximately 1 m since 1986.

At San Gregorio Creek the February 1986 storm waves moved the mouth against the north bluff, and the focused waves substantially scoured that portion of the beach, making it nearly as deep as areas under the bridge in 1986. The mouth returned to its former position, opposite the bridge, in 1987, and the "north embayment" has partially filled in.

Sandbar Formation and Inflow. Most of the depth of the summer lagoons is the result of ponding of streamflow and tidal overwash behind the sandbar; by the end of summer more than three-fourths of the lagoon water volumes is due to the inflows impounded by the sandbar. Lagoon depth and volume, however, are critically dependent upon the relative timing of bar formation and summer streamflow reduction. In 1985 streamflow was still relatively strong when the early sandbar formed at Pescadero Creek (Table 1); the lagoon rapidly filled in May (Figure 2). In 1986 streamflow was relatively low by the time the sandbar formed in July (Table 1), and the lagoon filled much more slowly (Figure 6). September rain and reduced agricultural diversions pushed the lagoon level up again in September and October 1986. In 1987 the sandbar was partially formed by March and fully closed by late March, when streamflows were still high (Table 1); early lagoon water levels were quite high, but progressively declined over the summer due to low inflows and sandbar seepage (Figure 10, Table 2). In 1988 the sandbar again formed early and the lagoon was deep in April. However, a late April storm breached the sandbar, and when the bar re-formed in late May streamflows were insufficient to achieve former lagoon levels (Figure 10, Table 1). Lagoon level progressively declined throughout the summer, due to sandbar seepage and evaporation, but November rain and runoff quickly brought up lagoon water levels (Figure 10).

At San Gregorio Creek early sandbar formation in 1986 (due to the change in location of the mouth) resulted in extremely high lagoon water levels, before the sandbar was breached in early July (Figure 22). Streamflows were sufficient in summer of 1986 to raise lagoon water levels each time the sandbar re-formed (Figure 22). In 1985 the mouth was displaced to the south by littoral sand movement and did not close off completely until after streamflows had declined greatly; the lagoon remained quite shallow all summer. In 1987 and 1988 the sandbars formed early, but lagoon water levels progressively declined over the summer due to low streamflows (Figure 27, Table 2), and the lagoon was quite shallow in late summer. In 1989 the sandbar formed in mid July, and the lagoon remained shallow until October rains (Figure 27).

The sandbars at Waddell Creek formed in early July in both 1985 and 1986. Because of the higher streamflows after bar formation in 1986, the water levels rose quickly before the bar was apparently artificially breached. In 1987 and 1988 sandbars formed early, but lagoon water levels fluctuated substantially with the rate of diversion upstream (Figure 36). In 1989 late June sandbar formation and upstream diversion kept the lagoon relatively shallow until inflows increased after mid August (Figure 39).

Pomponio Creek seldom has significant flow by the time the sandbar forms in summer, and the lagoon contained mostly impounded tidal flows and ocean overwash. Its depth remained less than 1 m until fall rains provided some freshwater input to the lagoon.

Highest lagoon water levels usually occur in late fall or early winter, when mild, early storms increase freshwater inflow but waves are insufficient to breach the bar. In 1986 mild fall storms produced extremely high water levels at Waddell Creek, doubling the normal lagoon size and flooding areas north of the creek and east of Highway 1. Concern about flooding and high water tables of unleveed agricultural lands at Pescadero Lagoon resulted in artificial breaches of the bar by farmers in late October 1985 and 1986. In both cases the sandbar reformed after several weeks, high waters returned, and a second excavation of the bar was performed (Figures 2 and 6).

Seepage Through the Bar. Seepage through the bar is potentially sufficient to stabilize lagoon water levels at low inflows. However, since seepage depends upon lagoon water level and the hydraulic pressure that it provides, rising waters may not stabilize until the lagoon is quite deep (Figure 2). Lagoon depths at Pescadero, San Gregorio, and Waddell creeks appeared to stabilize at a maximum of 2 - 2 1/2 meters (6 - 8 feet), or about 1 - 1 1/2 m (3 - 5 feet) above the level of the open estuary, even at high inflow rates such as those occurring with the first fall rains. At lower inflows, such as those experienced in 1987 - 1989, lagoon water levels were much lower, and progressively declined throughout the summer due to sandbar seepage and evaporation (Figures 10 and 27).

When summer lagoon levels become very low, due to low freshwater inflows and/or to evaporation (Figures 10 and 27), seepage from the ocean through the sandbar can possibly occur at high tide. This seepage could increase salinity stratification or mean salinity of the lagoon. In 1988 at San Gregorio Lagoon significant ocean seepage may have entered the lagoon, as bottom salinities increased 5 PPT between 7 August and 30 October (Figure 30).

Tidal Overwash. After bar formation daily high tides often continue to wash over the bar for several weeks. Some overwash may occur during extreme high tide periods throughout the summer. However, the volume of this addition to the lagoons is usually relatively insignificant compared to freshwater inflow. Pescadero Lagoon in early June of 1985 increased in height 0.3 feet during 3 nights of high tide overwash (0.1 feet/day); however, in the 4 cloudy days prior to the overwash the lagoon increased in height nearly as much (0.35 feet or 0.09 feet/day) due to freshwater inflow. In smaller lagoons or those with little freshwater inflow the effect of overwash is greater. At Waddell Creek lagoon in July 1986 overwash increased the lagoon height by 0.2 feet in one afternoon. Pomponio Creek lagoon, which receives little summer freshwater inflow, appears to depend upon overwash of the forming sandbar for 1/4 to 1/2 of its summer lagoon water volume.

Despite occasional tidal overwash, Pescadero, Waddell, and San Gregorio lagoons were gradually converted to substantially freshwater conditions (salinities less than 2 PPT) by freshwater inflow in the summers of 1985 and 1986. Only Pomponio Creek Lagoon remained very brackish in summer.

Channel Volume. Pescadero lagoon spreads over an extensive area of low gradient streambed and adjacent wetlands, and substantial inflow is required to raise the water level. In 1985 inflows of greater than 5 cfs raised the water level only about 3 feet in 5 weeks (Figure 2). Even in Fall of 1985 light rains took nearly 2 weeks to raise the lagoon a similar amount. The narrow, incised channels of Waddell and San Gregorio Creeks require less inflow to increase lagoon depth. Waddell Creek lagoon rose approximately 2 feet within one week of sandbar closure in July 1986. Early bar closure at San Gregorio Creek resulted in approximately a 4 foot rise in 2 weeks in June 1986 (Figure 22) at streamflows of approximately 7 cfs (Table 1); lagoon levels at San Gregorio lagoon continued to sharply rise after each sandbar closure throughout the summer (Figure 22).

Leveed Marshland. At Pescadero nearly 1/2 of the normally-flooded wetlands complex is behind levees. North Marsh and North Pond (map in appendix) are connected to each other by one 10 inch diameter culvert and to the remainder of the complex by one 10 inch diameter culvert. East Delta Marsh flows via a tide gate. All of these structures greatly restrict water movement and water level fluctuation. The Butano Marsh levees have small breaches which restrict tidal movements when the lagoon is open, but do not restrict the extent of flooding after sandbar closure. The elevation of the culvert from Pescadero Creek to North Marsh allows water to enter North Marsh only after the lagoon water level has reached approximately 4 feet on the Highway 1 staff gage; the sandbar must be in place to raise the water level that high. In wet years the lagoon rises rapidly above that level, then water siphoned into North Marsh slows the rise in depth in the nonleveed portion of the preserve. The loss of water to North Marsh may be a factor in the lowering of main lagoon depth in late summer (Figures 2 and 10). The lag in water movement through the culvert also operates in winter when the sandbar is breached and the main lagoon level drops. At that time North Marsh water levels are considerably higher than in the lagoon and only slowly subside.

In February 1986 flood waters topped the north levee along Pescadero Creek and flooded North Marsh to the highest levels encountered during the study. Loss through the culvert brought the Marsh water level to the bottom of the culvert by June. Levels continued to drop (due to evapotranspiration) for another month, producing the lowest water levels of the year. Rising lagoon water levels then began to feed into North Marsh. North Marsh usually retains considerable water under the present levee arrangement, while other marshlands within the system, such as Butano Marsh are completely drained when the bar is open. During 1988, however, North Marsh water levels declined due to low summer water levels in the main lagoon (Figure 10) and reduced flow through the culvert. In 1989 artificial breaching of the sandbar in summer, to facilitate construction of the new Highway 1 bridge, eliminated most culvert flow from the lagoon. North Marsh dried up, except for the ditch around the edge of the marsh.

Because so much of the marsh is diked off, with small culverts or tide gates, the main lagoon rises and converts to freshwater faster than if the entire system were open to unrestricted water movement; however North Marsh does begin to siphon off water long before adjacent agricultural lands are flooded. The flow rate through the culvert increases with the height (and hydraulic pressure) of the main lagoon, thus acting as a "safety value" to slow the rise in lagoon height with the first rains in fall. In September and October 1986 about half of the increased freshwater inflow to the lagoon was siphoned off into North Pond and North Marsh.

Salinity

Mean salinity and salinity profile in the lagoon are dependent upon freshwater inflow, the amount of impounded salt water at the time of sandbar formation, channel volume and depth, seepage and overwash at the sandbar, and mixing of the water column by wind. The salinity of portions of the marsh at Pescadero is also dependent upon circulation patterns.

Freshwater Inflow. After bar formation the heavier salt water forms a layer on the bottom of the lagoon. This layer is gradually lost by seepage through the bar and by mixing and dilution with the lighter freshwater inflow. In 1985 the freshwater inflow quickly converted Pescadero Creek lagoon into a freshwater system for the summer (Figure 3, Table 2). In 1986 streamflows were lower prior to sandbar formation (Table 1), resulting in more saltwater in the lagoon at the time of bar formation and much slower conversion to a freshwater lagoon (Figures 7A and 7B). Much of the lagoon had salt water lenses on the bottom for the entire summer. In 1984 the sandbar was breached early in the summer at Pescadero and the meager inflows after breaching did not convert the lagoon fully to freshwater (less than 2 PPT) until late October. In 1987 and 1988 low streamflows after sandbar formation were insufficient to convert the lagoon to freshwater; most of the lagoon remained saline and stratified for salinity all summer (Figures 11 and 13, Table 2).

San Gregorio converted to an unstratified low salinity system after sandbar closure in 1985 (Figure 19, Table 2). In 1986 the sandbar was repeatedly breached (Figure 22), so conversion to fully freshwater conditions never occurred. However, streamflows were sufficient to reduce lagoon salinity after each new sandbar formed (Figure 23, Table 2); if the early sandbars had not been breached, full conversion to freshwater would certainly have occurred. In 1987 summer streamflows were very low and the lagoon remained brackish and stratified all summer (Figure 28). The salinity of the lagoon did substantially diminish immediately after sandbar formation in 1987, while freshwater inflows persisted, and diminished further with late October rains and increased streamflow (Figure 28, Table 2). However, no significant change in lagoon salinity occurred in late summer (11 August - 18 October), when freshwater inflows were negligible. In 1988 the lagoon was partially converted to freshwater by 18 April, behind the early sandbar, but a late April storm breached the sandbar (Figures 27 and 30). When the sandbar reformed, streamflows were too low to substantially reduce lagoon salinity (Figure 30, Table 2); the lagoon remained stratified and very saline all summer. In 1989 low streamflows after sandbar formation kept San Gregorio Creek lagoon shallow, stratified, and very saline until streamflows increased in September and October (Figures 27 and 33).

Waddell Creek lagoon converted fully to freshwater in 1985, 1987, and 1988. In 1987 the sandbar formed in mid to late May and a salt water lens about 1 m deep remained on the bottom of the 2.8 m deep lagoon on 7 June. The lagoon was fully converted to freshwater by 6 August, but most of the conversion must have occurred in June, as streamflows ceased below the upstream diversion in July (Linda Ulmer, formerly DFG, pers. comm), resulting in a sharp drop in lagoon level (Figure 36). In 1988 the lagoon was mostly converted to freshwater by 18 April, following early sandbar formation (Figure 37). The sandbar was breached on 22 April, following a late storm, and the sandbar re-formed just prior to 12 May. Little salt water entered the lagoon between the breach of the first sandbar and the formation of the second, so the lagoon was still mostly freshwater on 12 May (Figure 37). The lagoon was converted fully to freshwater by 29 June, due to sandbar seepage and freshwater inflow. In 1989 substantial conversion to freshwater occurred between 6 May and 28 May behind a partially open sandbar (Figure 40). On 21 June the outlet was much wider and deeper, and lagoon salinities were much higher (Figure 40); apparently tidal scour or sandbar formation and breach had opened the lagoon to greater tidal influence. When the sandbar finally formed in late June streamflows were low enough so that stratified saline conditions remained for the rest of the summer (Figure 40). Streamflows greatly increased following reduced fall diversions and rain on 18 September, and the lagoon further converted towards freshwater in September and October (Figure 40).

Pomponio Creek lagoon remained very saline in 1985 and 1986 because of lack of freshwater inflow in summer.

Lagoon Water Level and Sandbar Seepage. Seepage of the saltier water through the base of the sandbar is substantial and is one of the factors leading to the conversion of the lagoon to freshwater as the summer goes on. The slope of the lagoon bottom is generally towards the sandbar, resulting in movement of the heavier salt water towards the bar. However, the irregular bottom of much of the lagoons still results in isolated lenses of salt water in the depressions. Because of past sedimentation, most of the lagoon volume of a closed lagoon is "perched" above low tide ocean level, allowing percolation through the sandbar. The deepest water is subject to the greatest hydraulic pressure and in these shallow, perched lagoons moves more quickly through the sandbar. The deepest water is also the saltiest, resulting in the preferential seepage loss of the bottom salt water layer. The process is well shown by the earlier loss of the saltiest layers during the process of conversion of the lagoon to freshwater (Figures 3, 7B, 13, 28, 40).

If the very deepest portions of the lagoon are lower than the ocean low tide level the seepage rate is probably lower, due to upstream water pressure in the sandbar from the ocean. However, even then there will be seepage out from the lagoon if lagoon water levels are substantially above ocean levels, so that downstream water pressure is greater.

Seepage is important to lagoon conversion, and lagoon water elevation and the hydrostatic pressure created determine the rate of seepage. Therefore, lagoons with higher water levels should convert faster to freshwater. At San Gregorio Creek lagoon the initially deeper lagoon in 1988 required a substantially smaller rate of freshwater inflow per percent reduction in lagoon salinity than did the shallow 1987 lagoon (Table 2).

Amount of Impounded Salt Water. Obviously, the greater the amount of the impounded salt water after sandbar formation, the more freshwater inflow necessary for dilution. Also, more saline lagoons will take longer to convert to freshwater, because the loss of the salt water due to seepage through the sandbar will take much longer. The late sandbar closure at Pescadero lagoon in 1986 resulted in progressively more saline conditions prior to closure (Figure 7A), and the lagoon did not convert to freshwater until fall (Figure 7B). In 1988 Waddell Creek lagoon contained little salt water at the time of sandbar formation and was quickly converted to freshwater (Figure 37), but in 1989 Waddell lagoon was very saline after sandbar formation and never did convert to freshwater conditions (Figure 40).

Because of the variation in the relative timing of bar formation and decline in streamflows, the amount of salt water present immediately after sandbar formation will vary substantially from year to year. In years of early streamflow decline and relatively late sandbar formation (such as 1988), the lagoon may exceed 60 percent salt water immediately after sandbar formation (Table 2).

Channel Volume. Channel volume not only affects the rate of lagoon filling, but also the potential rate of conversion to fresh water. Pescadero lagoon converts more slowly to fresh water after sandbar formation, because so much salt water must be diluted and displaced. Pescadero Creek lagoon required an average of three times as much inflow to achieve the same amount of salinity conversion as did San Gregorio Creek lagoon from 1985 through 1988 (Table 2).

Although the sandbar at the much smaller Waddell lagoon usually forms one month after the bar at Pescadero Creek (Table 1), Waddell Creek lagoon usually converts fully to freshwater earlier. Although Waddell Creek lagoon did not convert to fresh water in 1989, it did in 1987 and 1988. Both Pescadero and San Gregorio creek lagoons remained very saline throughout the summer in the 1987-1989 drought years.

Tides and Overwash. While the sandbar is still partially open, substantial saltwater enters with the high tides. The bottom of the lagoon/estuary can be quite saline at this time, despite freshwater inflow, because the heavier salt water does not leave with the outgoing tide. For example, on 8 June 1986 at Waddell Creek lagoon the salinity of outflow from the lagoon was 4.3 PPT, while the bottom 1/2 to 2/3 of the lagoon had salinities of 23 - 28 PPT. The differences in salinity between inflow and outflow through the opening in the bar become greater as the sandbar progressively closes.

As indicated in the discussion of lagoon depth, overwash of a full sandbar contributes little to the total water volume of Pescadero, San Gregorio, and Waddell lagoons. However, the overwash is much saltier and usually colder than the lagoon water, and because of its high density, even a small amount can spread out and sharply increase salinity on the bottom of the lagoon. For example, a late October storm in 1985 apparently resulted in tidal overwash, as well as freshwater inflow, at San Gregorio Creek lagoon; the storm produced both a freshening of surface waters and a salt water lens on the bottom of the lagoon

(Figure 19). In the absence of strong mixing in the lagoon, these salt water lenses may persist for several weeks.

Wind. The density differences between the different salinity layers is sufficient to prevent mixing in the absence of strong wind and wave action. In the narrow, vegetation-lined, upper stream channels of the lagoons wind mixing is poor in the deeper portions of the channel. In 1986 in Pescadero Creek lagoon these were the last areas to retain salt water lenses on the bottom, although they were closest to the freshwater inflow. In June 1985 on San Gregorio Creek a deep pool at the upper limits of the lagoon contained salt water on the bottom, even though surface waters and shallower portions of the lagoon downstream were freshwater; the site was also upstream of a rancher's diversion intake. However, prolonged windy periods can lead to considerable mixing, especially in the relatively wide, main embayments of the lagoons (immediately upstream of the Highway 1 bridge at Pescadero Creek and downstream of the bridges at San Gregorio and Waddell creeks). In the brackish lagoon at Pescadero in 1987 the main embayment was unstratified by 1 September (Figure 11), due to wind mixing of the unusually shallow lagoon. However, all of the wind-sheltered sites upstream of the main embayment remained stratified.

Circulation Patterns. At Pescadero Marsh NP the salinity of channels in Butano Marsh in late summer was often higher than for the rest of the lagoon complex. For example on 29 July 1985 most of the Pescadero lagoon complex had salinities of 1.3 PPT or less. In Butano Marsh the salinity was 2.0 - 3.1 PPT. One of two openings from Butano Creek into the marsh is at the downstream end of the marsh, and freshwater circulation into the marsh is restricted during summer. The second opening, constructed in 1985, is at the upstream end of the marsh, but its high elevation allows freshwater flow through the marsh only during winter runoff periods.

The culvert connections from Pescadero Creek to North Marsh and then to North Pond reduce salinity variation in those habitats and greatly restrict the range of salinity of the inflows to them. The main lagoon siphons water into North Marsh only when the sandbar is in place and the lagoon fills to above 4.2 feet. In addition, since only the less saline surface waters flow through the culvert, the marsh normally receives mostly freshwater input. For Example, on 23 July 1986, only several weeks after sandbar closure, the lower half of the water column at site 18B on Pescadero Creek had salinities greater than 20 PPT, but the surface waters flowing through the culvert into North Marsh were only 4.6 PPT. In 1985, when the main lagoon converted quickly to freshwater, flows into North Marsh were closer to 1 PPT for much of the summer. Salinities in North Marsh were mostly between 3 and 4 PPT in 1984 but declined to between and 2 and 3 PPT in 1985 and 1986. North Pond and North marsh are usually shallow and wind-swept, and are therefore not stratified. The culvert between them is not near the surface, so there is no differential movement of fresher waters between them. North Pond and North Marsh rose and fell together, and water exchange appeared to gradually equalize salinities in the two habitats from 1984 to 1986. In September 1984 North Pond had salinities above 7 PPT; by October 1985 its salinities had dropped to 3.2 - 3.6 PPT.

The salinity of North Marsh and Pond probably fluctuates with yearly runoff conditions. Culvert flow into the marsh is more saline during drought years (such as 1987), while in most years freshwater flows dilute the marsh. In 1987, drought conditions produced early sandbar closure at Pescadero, but only very slow conversion of the lagoon to fresh water. Saline water (4+ PPT) flowed into the marsh during April and May, raising the salinity of the marsh.

Evaporation. In years of little summer inflow, evaporation within shallow lagoons can substantially increase salinity. In 1988 mean lagoon salinity increased from August through October at San Gregorio and Pescadero creek lagoons (Figures 14 and 30). The effect was most pronounced for North Marsh at Pescadero NP, where lack of inflows in 1988 and 1989 resulted in drying of most of the marsh in 1989 and very saline water water (10 - 15+ PPT) in the ditch surrounding the marsh.

Temperature

Lagoon water temperatures were dependent salinity conditions, tidal mixing, shade and weather.

Salinity. Stratification by salinity also resulted in temperature stratification in the lagoons. In these shallow (2 m) lagoons daytime heating occurred throughout the water column, but only surface waters were able to lose heat at night. Saline bottom waters acted as a solar collector and trapped the heat, resulting in progressively higher relative water temperatures within the salt water lens. In Pescadero Lagoon the saline bottom waters in July 1984 (Figure 1) and May of 1985 (Figure 4) did not mix with those above and had higher temperatures. In 1985 rapid conversion to fresh water resulted in thorough temperature mixing in the lagoon for most of the summer (Figure 4). In 1986, however, Pescadero Lagoon showed a variety of summer temperature profiles (Figure 8). Prior to sandbar closure the water was warmer at the surface, due to solar warming at the surface and tidal cooling at the bottom. After sandbar closure the saline bottom waters acted as a solar collector; bottom waters were warmest and the mean water column temperature was much higher than in 1985. In summer of 1987 and 1988 and spring of 1989 salinity stratification resulted in temperature stratification and very high lagoon water temperatures at Pescadero Creek lagoon (Figures 12, 14 and 17).

San Gregorio Creek lagoon was stratified for salinity in early summer of 1985 and throughout the summers of 1987, 1988, and 1989, and showed strong temperature stratification, with very high water temperatures within the bottom salt water lenses (Figures 20, 29, 31 and 34). By late summer of 1985 the lagoon had destratified for salinity, and water temperatures were much lower and not stratified (Figure 20). In 1986 repeated sandbar closure and breaching kept the lagoon stratified for salinity all summer (Figure 23). When the lagoon was closed, water temperatures within the bottom salt water layer quickly rose to 3 to 10 degrees higher than surface waters, and even reached 30 degrees C within the bottom salt water layer on 24 September (Figure 24). At upstream sites water temperatures in the bottom salt water layer were substantially higher than surface temperatures even when the lagoon was open to tidal mixing (Figure 25), because of solar heating of the bottom layers and lack of tidal cooling.

Waddell Creek lagoon converted to freshwater conditions in 1985, 1987, and 1988 (Figure 37), and water temperatures were cool and unstratified in those years (Figure 38). In 1986 sandbar breaching produced salinity and temperature stratification in the lagoon with high bottom water temperatures. In 1989 Waddell Creek lagoon remained stratified for salinity (Figure 40) and had high water temperatures within the bottom salt water lens in late spring and early summer (Figure 41).

In Pomponio Creek lagoon, which was both saline and shallow because of a lack of freshwater inflow, summer water temperatures in 1986 averaged greater than 27 degrees C. Near the bottom, temperatures exceeded 35 degrees.

Tidal Mixing. When fully open to tidal action the lagoons showed a variety of temperature patterns. Near the bar the tidal inflow of ocean water tended to keep water temperatures cool. Upstream, where tidal movement was attentuated, the saline bottom waters continued to collect heat. In San Gregorio Creek lagoon on 23 June 1986 water temperatures at the Highway 1 bridge and at a site even closer to the mouth averaged near 20 degrees C, with much cooler bottom waters (Figure 25). Upstream sites were warmer on the the bottom than at the surface and had bottom water temperatures reaching 23 - 26.5 degrees C (Figure 25).

In 1989 Pescadero Lagoon the sandbar was opened to aid work on the new Highway 1 bridge. Pescadero Creek lagoon's very large embayment produces good tidal exchange, and water temperatures within the open embayment were nearly as cool as the ocean (Figure 17).

Shade. Most the surface area of the lagoons is unshaded. However, in the upstream portion of Waddell Creek, riparian vegetation provides significant shading; water temperatures tended to be several degrees cooler. At Pescadero Marsh NP the coolest waters in 1985 and 1986 were at sites 15, 16 and upstream on Butano Creek, where the narrow channel and dense border of cattails, willows, and alders kept the water less than 20 degrees C all summer.

In 1988 at Pescadero Creek lagoon and 1989 at Waddell Creek lagoon dense pondweed growth restricted sunlight penetration to near the surface and reduced water column heating in late summer. The shading eliminated the temperature stratification and high bottom water temperatures that were present earlier in summer (Figures 14 and 41).

Weather. Water temperatures in the lagoons are very sensitive to periods of overcast, which reduce the heating of the lagoons. After nearly a week of overcast at Pescadero in summer 1985 water temperatures were reduced 2 - 3 degrees C. Daily temperature fluctuation in the top meter of the lagoons can be 2 - 4 degrees C on sunny days. In general, summer overcast appeared to occur less often and was less persistent south of Pigeon Point, so Waddell lagoon experienced slightly greater solar heating than the other lagoons.

Strong winds, which break up salinity and temperature stratification, tend to result in lower average lagoon temperatures. Winds can quickly bring unstratified lagoon waters to near average air temperature, and are responsible for much of the rapid cooling that usually occurs in October.

Dissolved Oxygen.

Dissolved oxygen is affected by salinity and temperature stratification, tidal and wind mixing, abundance of aquatic plants, and presence of decomposing organic matter.

Salinity and Temperature Stratification. Salinity stratification usually resulted in pronounced dissolved oxygen stratification in the lagoons. After sandbar formation saline bottom waters often became anoxic because of a lack of mixing; this condition usually persisted until freshwater inflow and wind mixing broke up the salinity stratification. In 1986 bottom anoxia quickly followed mid July sandbar formation at Pescadero Creek lagoon (Figure 9), although dissolved oxygen was supersaturated near the top of the saltwater lens. In 1989 bottom oxygen sharply dropped following sandbar formation in both mid May and September (Figure 18). In 1988 the bottom still had high oxygen levels one month after sandbar formation (27 June), but was anoxic in late summer and fall (7 August and 30 October) (Figure 15). When algae was present on the bottom or pondweed was abundant, extreme diurnal fluctuations in dissolved oxygen often occurred, with supersaturated conditions in late afternoon due to photosynthesis and anoxia by morning due to respiration (Figure 1). Artificial breaching of the sandbars at Pescadero Creek lagoon in fall of 1985 and 1986 resulted in a return of stratification and anoxia of bottom waters.

San Gregorio Creek lagoon had low dissolved oxygen levels at the bottom of the salt water layer after each sandbar closure in 1986 (Figure 26). In 1988 the stratified, brackish lagoon had very low dissolved oxygen levels at the bottom of the salt water layer throughout August through November) (Figure 32), despite the shallowness of the lagoon (approximately 1 m).

Waddell Creek lagoon had high water column dissolved oxygen levels in the unstratified, freshwater lagoons of 1987 and 1988, but low bottom dissolved oxygen levels in the brackish, stratified 1989 lagoon (Figure 42).

Tidal and Wind Mixing. Highest dissolved oxygen levels at the substrate occurred when the lagoons were open to full tidal exchange. After sandbar formation the deeper water, which was often below the compensation depth for aquatic plants, generally had low dissolved oxygen levels for at least part of the day. Low bottom oxygen levels tended to occur in the narrower channels of the lagoons, where wind mixing was reduced. When aquatic plants were not abundant, a period of calm days resulted in water column oxygen level drops of several Mg/l.

Aquatic Plants. Dense pondweed concentrations produced sharp diurnal swings in dissolved oxygen and persistent low dissolved oxygen levels in the lower half of the water column. In 1985 steelhead appeared to utilize areas of dense pondweed in channels in Butano Marsh (Pescadero Marsh NP) during the day and evening when oxygen levels were high and leave the marsh channels as oxygen levels dropped at night. The other areas where pondweed densities were high enough to seriously affect oxygen levels and fish populations in non-drought years, however, were in North Marsh at Pescadero Marsh NP. There the shallow water and silt bottom resulted in nearly 95% of the water column being filled with pondweed by the middle of summer. Under those conditions dissolved oxygen levels were extremely low (less than 2 mg/l) below approximately 0.25 - 0.5 meters deep. The deep channel along the west and south sides of the marsh did retain some open water with higher average oxygen levels, but even there oxygen was periodically severely depressed during overcast periods. Near midday at site 50 on 28 July 1985 the highest water column oxygen level was only 2.8 mg/l at the surface, and below 0.5 meters deep levels were 0.6 mg/l or less.

North Pond maintained a very persistent, dense phytoplankton bloom throughout the study, although density descreased in mid winter. Near-surface dissolved oxygen levels were high and usually super-saturated in the afternoon. Good wind mixing in the pond usually kept water column oxygen levels high, except in the protected channel near the levee separating the North Pond from North Marsh. The continuous dense bloom of phytoplankton suppressed pondweed growth, except for a small patch along the eastern shore.

Pondweed was generally more abundant in Pescadero, San Gregorio, and Waddell lagoons during the 1987, 1988 and 1989 drought years. Very Abundant pondweed in Pescadero lagoon in 1988 was responsible for very low dissolved oxygen levels in late summer (Figure 15); the pondweed shaded the bottom and kept the bottom anoxic, but also sharply reduced water column dissolved oxygen levels at night or during periods of overcast. High pondweed abundance at Waddell Creek lagoon was a factor in the low bottom dissolved levels present in late summer and fall of 1989 (Figure 42).

Most of the adverse water quality effects of pondweed or algae were observed in quiet backwaters (North Marsh) or in the drought years (1987-1989) when lack of winter scour allowed early growth and high pondweed density. However, the adverse effects are probably more likely to occur in a stratified lagoon; the higher bottom temperatures probably stimulate growth rates, and the lack of vertical mixing makes dissolved oxygen fluctuations more severe.

Decomposing Organic Matter. Pondweed died back in the lagoons in late October and November 1985, probably due to cooler water temperatures (Figure 5). Increased turbidity with first rains and tidal currents after sandbar breaching may have also contributed to the die-back. Oxygen levels were somewhat depressed by dead pondweed in the upper arms at Pescadero lagoon, but not in those areas subject to significant wind or tidal action; mixing by the winds and tides kept oxygen levels high.

Sandbar breaching at Waddell Creek in early July 1986 also allowed tides to bring in piles of kelp, which decomposed and used up most of the dissolved oxygen in the lagoon (Figure 35). Although tidal inflow at high tide partially restored dissolved oxygen levels, at low tide the only oxygenated refuge for the fish was the 10 - 20 cm of freshwater inflow at the surface of the lagoon.

Phytoplankton

Phytoplankton densities began to increase in late spring, when the lagoons were still open to tidal mixing. Immediately after sandbar closing phytoplankton densities rapidly increased (and secchi depths decreased) for about 1 month. Once pondweed densities began to increase phytoplankton decreased, presumably due to competition with pondweed for nutrients. In late summer after pondweed was fully developed, phytoplankton was scarce and the lagoons relatively clear. After pondweed died back with cold weather in October, there was often another phytoplankton bloom.

Very low phytoplankton abundance was observed during the drought, presumably because of the usually abundant pondweed.

Aquatic Vegetation

The growth of filamentous algae and pondweed in the lagoons may periodically reduce dissolved oxygen levels, but it also provides food and substrate for invertebrates. Temperature and turbidity appear to control the timing of pondweed growth, and substrate and depth/turbidity appear to control the location of pondweed and sea lettuce (Ulva lactuca) in the lagoons.

Temperature. In Late October of 1985 water temperatures had dropped to 14 - 16 degrees C in Pescadero Creek lagoon, compared to 18-19 degrees C in early September, and most of the pondweed had died back (Figure 5). Water temperatures in late May were mostly less than 18 degrees C and pondweed growth had just begun. In 1986 the temperature regime and timing of pondweed growth was similar in the upper arms of the lagoon, despite the open sandbar and high salinities. However, pondweed growth in the main embayment was delayed compared to 1985. Stratified conditions in the upper arms resulted in warmer bottom waters compared to those in the tidally-mixed main embayment, and may have accounted for the difference in timing of pondweed growth between the two areas. In 1987 and 1988 the sandbars closed early (April), water temperatures and salinities were high, and pondweed growth was advanced about one month compared to 1985 and 1986.

Depth and Turbidity. When the lagoons rapidly fill after sandbar formation much of the deepest portions of the lagoons (such as the main embayment at Pescadero lagoon) are deeper than secchi disk depth, especially if phytoplankton densities are high. Although the lagoon gradually clears over the next 2 months, it is possible that pondweed and filamentous algae growth are suppressed in deepest portions of the lagoon (greater than 2 meters deep) by low light availability. The problem is probably greatest for algae, since the pondweed, once started, can grow rapidly towards the surface. The majority of filamentous algae in the lagoons was usually found growing on the upper portions of the pondweed.

Substrate. When open to full tidal action and for about a month after the bar has closed, sea lettuce can be present in Pescadero lagoon. In 1986, attached sea lettuce was found on the rocky ledges along the south side of the main embayment. Unattached sea lettuce was found primarily in the "null zone" of tidal mixing upstream of the main embayment near the confluence of Butano and Pescadero creeks (sites 7B, 8, 9, and 18B).

Pondweed appeared to be most abundant in areas of soft substrate. The Pescadero Creek arm at Pescadero lagoon normally receives considerable winter scour, has sandy to gravely substrate, and has meager pondweed growth. The Butano arm of the system has lower gradient, has finer substrate (silt-sand), and usually has dense pondweed. In 1986 the February storms removed much of the finer silt in the Butano Creek arm and in the main embayment, and pondweed abundance was greatly reduced. Pondweed was still abundant in 1986 in the area of silt deposition near sites 8B and 9 and in the shallow portion of the main embayment upstream of the Highway 1 bridge. In 1987 and 1988 lack of winter scour at Pescadero lagoon resulted in abundant pondweed throughout the main embayment by the end of May. In 1989 the sandbar at Pescadero was kept open, and the pondweed was less abundant in the areas subject to tidal scour and cooling.

At San Gregorio and Waddell creeks, the incised channels and normally greater winter scour result in less pondweed than in Pescadero lagoon. Most of the pondweed is upstream of the Highway 1 bridges, where spring tidal scouring of the sand does not occur. Lack of flood scour in 1987, 1988, and 1989 resulted in much higher pondweed abundance. The pondweed acted as sediment trap in the mild winters, producing the thick deposits of fine sediment in which it seems to be most successful.

Toxic Inflows

Intensive agriculture surrounds portions of Pescadero Marsh NP, especially along the eastern bank of Butano Creek. In May 1986 at Pescadero Lagoon pesticides in runoff water entered the Butano Creek arm as the tide was ebbing. The pesticide was pulled down the Butano Creek arm of the lagoon and eliminated all fish and invertebrates in the arm. Freshwater flow down Pescadero Creek and tidal mixing appeared to have diluted the pesticide and no mortality was observed in the main body of the lagoon. The stratified estuary may also have kept the pesticide suspended and away from benthic invertebrates. The incident would have gone unnoticed if water quality sampling had not been taking place at exactly the time and place of the kill; hungry birds rapidly cleaned up most of the dead and dying fish and invertebrates.

Upstream Habitat

Habitat conditions in the lagoons cannot be treated as independent of upstream habitat and land use conditions in the watershed. In addition to the potential of toxic inflows from agricultural (or urban) areas, the lagoons were affected by sediment conditions, water temperatures, and flow rates in the streams entering the lagoons.

Substrate and Sediment. The developed upstream watersheds on San Gregorio and Pescadero creeks are contributing tremendous quantities of sediment to the downstream stream channels and lagoons. The lagoons may no longer suffer much additional filling, because they have become so shallow that scour and filling may be nearly balanced. However, the wintertime cycles of deposition and scour probably have severe effects upon benthic invertebrates. The influx of fine sediment also contributes to winter turbidity of the estuary, making it much less suitable as a feeding area for steelhead smolts.

Sedimentation of the stream channels upstream of the lagoons at San Gregorio and Pescadero creeks has also severely reduced the quality of spawning substrate for steelhead. The juvenile steelhead which populate the lagoons in summer now hatch far upstreamand in far fewer numbers. Undoubtedly fewerjuvenile steelhead utilize the lagoons than in the past, when significant spawningtook place near or in channels inundated by thesummer lagoons. At Waddell Creek the stream above the lagoon is largely protected and relatively undisturbed. Substantial spawning takes placeimmediately upstream of the lagoon and large numbersof juvenile fish are able to easily migrate the short distance to the lagoon. The lagoon at Waddell Creek, although much smaller than either San Gregorio or Pescadero lagoons, may rear more juvenile steelhead in some summers than the other two lagoons combined.

Temperature. Summer water temperatures upstream of the lagoons at San Gregorio and Pescadero creeks may represent an additional problem for juvenile steelhead attempting to move downstream to utilize the lagoons. At San Gregorio Creek the stream channel above the lagoon is broad and unshaded, and water temperatures are very high by early summer. On 19 June 1986 water temperatures in the stream immediately above the lagoon had reached 24.8 - 26.3 degrees C by 14:40 in the afternoon; they had increased 3 degrees C since 12:30 and probably reached 28 degrees

C by 16:00. At Pescadero Creek the channel upstream from State Park property is leveed, shallow, and sparsely shaded. On 3 July 1986 water temperatures climbed from 21.5 degrees C at 11:45 to 26.5 degrees C by 16:00.

Temperatures of streamflow into the lagoons probably have only minor effects on summer lagoon water temperatures. However, at Pescadero Creek lagoon the coolest summer lagoon water temperatures are in the upper Butano Creek arm, where well-shaded Butano Creek discharges into a narrow, and equally well-shaded portion of the lagoon.

Streamflow. Agricultural pumping takes place on San Gregorio, Pescadero, and Waddell creeks. The sharp reductions in streamflow that accompany the pumping season greatly affect the rate of lagoon filling behind the sandbars and thus the depths, salinities, temperatures and dissolved oxygen levels in the lagoons. The most dramatic effects of diversions are seen at Waddell Creek lagoon, because its small volume responds more quickly to changes in streamflow (Figures 36 and 39), but the water quality and size of all three lagoons are severely impacted by diversions, especially in dry years.

Invertebrates

Analysis is continuing on the invertebrate populations of the Pescadero Creek lagoon and their environmental determinants. However, some generalizations can be made at this time. Salinity, dissolved oxygen, plant and detrital food base, and substrate are probably the most important factors in invertebrate abundance and composition.

Salinity. Some small rock crabs (Cancer antennarius) entered Pescadero Creek lagoon when the system was open to full tidal exchange in spring. They were not abundant in spring and were not found long after the sandbar formed and the lagoon began to convert to freshwater. In 1986 when the lagoon was open until mid July and in 1989 when it was open most of the summer the crabs were quite abundant.

Shrimp (Neomysis sp.) are very abundant in Pescadero Creek estuary before formation of the sand bar. Highest concentrations are usually from the Highway 1 bridge upstream to the confluence of Butano and Pescadero creeks. Tidal action appeared to concentrate them at the entrance to Butano Creek (Site 8B); the area is also a zone of sediment and detrital deposition. The shrimp gradually declined after bar formation in 1985 and 1986 and were rare by late summer. Since they are primarily a particulate feeder, their abundance probably declines due to the replacement of phytoplankton with pondweed after the sandbar closes. They almost completely disappeared through 1987 and 1988, with early sandbar closure, clear water, and dense pondweed growth. They persisted in abundance in mildly brackish (3 PPT) North Marsh throughout the summer of 1985 and 1986. Neomysis were usually relatively rare in San Gregorio, Waddell, and Pomponio creeks. The lack of a large protected embayment in winter and the lack of protection provided by flooded vegetation in summer may be responsible. Phytoplankton blooms are also less common and dense than in Pescadero Lagoon. The very rapid potential conversion of those small systems to freshwater after sandbar formation may also be responsible.

Euryhaline amphipods (Gammarus spp. and Corophium spp.) were present throughout the year in the lagoons. Their abundance appears to depend more upon detritus availability, dissolved oxygen, and substrate conditions than upon salinity.

Freshwater insects, especially diving beetles (Dytisidae), water boatmen (Corixidae), and midge larvae (Chironomidae) became abundant in the pondweed after the lagoons converted to freshwater. They were especially abundant in Pescadero lagoon in 1985, as were freshwater snails (Physa and Gyralus).

Dissolved Oxygen. When the estuaries are open to full tidal mixing, dissolved oxygen levels are high in most of the systems, even at the substrate in deeper waters. After bar formation the rapid rise in water level and accompanying salinity stratification resulted in anoxic conditions at the substrate in the deeper waters (Figures 9, and 15), eliminating the amphipods from those areas. As salinity stratification is eliminated by freshwater inflow and wind action, oxygen conditions and invertebrate populations recover. The loss of invertebrates from the deeper parts of the channel during the transition from tidal conditions to freshwater is compensated for by the flooding of additional areas as the waters rise. However, the incised channels and relatively level cross-sections of much of the upper portions of Pescadero (sites 9 - 14 and 18B - 24), San Gregorio, and Waddell creeks results in severe invertebrate depressions in those areas during the transition; the only habitat available is on the vertical portion of the banks above the salt water lens.

Temporary artificial breaching of the sand bars in summer returns salinity stratification and bottom anoxia (Figures 23 and 26). Invertebrate populations again crash as the lagoon goes through the transition to freshwater. Continuous breaching, such as occurred at San Gregorio lagoon in summer 1986, results in low overall invertebrate abundance.

Plants and Detritus. Amphipod populations, especially of Gammarus, were extremely abundant in detritus provided by dislodged sea lettuce and by pondweed and algae.

Diving beetles and water boatmen were most abundant in the dense stands of pondweed. The boatmen presumably feed on decaying pondweed and the algae growing on the pondweed. Their eggs are also laid on the pondweed. Snails were abundant on the pondweed, and apparently fed on periphyton on the pondweed.

Sections of the lagoon without dense pondweed or algae still had dense populations of Corophium when tidal action was present, such as in early summer 1986 and 1989 at Pescadero Lagoon. Tidal action presumably disperses fine detrital matter throughout the lagoon. The dense populations of Neomysis in portions of the tidal lagoon is probably in response to detrital particulates concentrated in the water column and at the substrate surface, as well as phytoplankton blooms.

Substrate. Tube-building Corophium were most abundant in sand and sand-silt substrates; they were rare in coarser sand- gravel or very fine silt substrates.

The first storms of winter in 1985 and 1986 deposited very fine silt in Pescadero Lagoon. The silt, which came from the agricultural lands surrounding Pescadero and Butano creeks, was thickly deposited throughout the lagoon, destroying most of the benthic invertebrates. The 1 to 6 inch thick carpet persisted for several months, until later and stronger winter storms removed most of it. In years with only very mild storms the fine silt might persist through the entire year, severely reducing invertebrates as food for fish.

Fishes

Twenty-five species of fish were collected from the four estuary/lagoon systems in 1984 - 1989 (Table 3). The number of species was greatest for Pescadero Creek lagoon and decreased with the decreasing size of the lagoons. The number of species in Pescadero Creek lagoon was greatest in 1986, when delayed sandbar formation allowed eight species of juvenile saltwater fishes to enter the estuary through mid July. Although the sandbar at Pescadero Creek was open through much of the summer in 1989, the only strictly saltwater juveniles found in September were cabezon (Scopaenichthes marmoratus).

All four lagoons shared five species of euryhaline fishes: threespine stickleback (Gasterosteus aculeatus) and prickly sculpin (Cottus asper), which were also present in the streams above the lagoons; steelhead, which were hatched upstream and used the lagoon for rearing or as a migration pathway; and staghorn sculpin (Leptocottus armatus) and starry flounder, which hatched in salt water and entered the lagoons in winter or spring for one to two years of rearing. Large resident populations of tidewater goby (Eucyclogobius newberryi) were present in Pescadero and San Gregorio creek lagoons; they were present in Waddell Creek lagoon until 1973 floods (Dr. Camm Swift, L.A. County Museum, pers. comm.).

The large estuarine embayment, with good tidal exchange, appeared responsible for the high diversity of species present in Pescadero Creek lagoon in 1986. Conversion of the lagoon to freshwater after sandbar formation in 1986, however, appeared to eliminate saltwater species and even some euryhaline species, such as shiner perch (Cymatogaster aggregata) and topsmelt (Atherinops affinis). Tidewater goby, which is normally common in Pescadero Creek lagoon, was extremely rare in the main embayment in 1989, apparently because it avoids areas of strong tidal mixing; in 1986 they only became abundant in the main embayment several months after sandbar closure.

In the brackish Pescadero Creek lagoon of 1988 topsmelt and shiner perch survived all summer, and shiner perch were the most abundant fish in November. Low dissolved oxygen, high water temperatures, and very low invertebrate abundance were present in the brackish lagoon in late summer 1988 (Figures 14 and 15). Stickleback, steelhead, staghorn sculpin, and starry flounder numbers drastically dropped from August to November, and Pacific herring (Clupea harengus), the second most abundant fish in August, disappeared by November. At San Gregorio Creek lagoon in 1988 water quality conditions were similarly poor and steelhead and staghorn sculpins, which are normally abundant, were rare by December.

Natural history accounts for the fish species for 1984 - 1986 are given in Smith (1987). Steelhead sampling results for 1985 - 1989 are treated in detail below.

Steelhead Trout

Significance of the Lagoons to Steelhead. San Gregorio, Pescadero, and Waddell creek lagoons can be heavily used by juvenile steelhead for rearing, despite their shallowness and warm summer water. For Pescadero lagoon in 1986 the best estimates of large fish (mostly 100 - 200 mm standard length, see Figure 45) using the main embayment were 6308 on 28 July, 7422 on 26 September, and 9893 on 28 November; three estimates for the number of steelhead in the entire lagoon complex on 28 November all exceeded 17,000. At San Gregorio lagoon the 19 October 1986 estimate, based upon fish marked in June and July, was 10,713. At Waddell lagoon the 12 October 1986 estimates, based upon fish marked earlier in the summer, ranged from 8653 to 14,716. Four estimates for the number of yearling steelhead in Waddell lagoon in July and October 1986 ranged from 2032 to 2654. In addition, most of the lagoon fish had grown big enough to smolt and enter the ocean by the end of the year (Figures 45, 48, and 51).

To put the above figures in perspective they should be compared to steelhead production in the watersheds. At Pescadero Creek, November 1986 estimates of stream densities of steelhead at two representative sites (far upstream, above the degraded lowland habitat) averaged 2368 fish per mile. It would take 8 miles of stream to equal the numerical production of steelhead in Pescadero lagoon in 1986. When fish size is taken into account the value of the lagoon is even greater. In the stream there were only an estimated 467 fish per mile that were longer than 100 mm SL. The entire 25 miles of accessible streams in the watershed would probably be able to produce only two-thirds as many large fish as the lagoon, and those fish would still be smaller than most of the fish reared in the lagoon (Figures 44 and 45).

Analysis of scales from 27 adult steelhead collected on Pescadero Creek from 1985 - 1989 showed that 16 fish, or 59.3 percent, reared in the lagoon (Table 4). Another 2 fish (7.4%) spent their first year in the stream and their yearling year in the lagoon, and 1 fish (3.7%) spent 2 years in the stream, but grew 40% of its length in the lagoon before entering the ocean in 1986. At least 70 percent of the adult steelhead in this limited sample reared in the lagoon. In addition, 5 of the fish (18.5%) had back-calculated first year sizes intermediate between those of fish collected in the stream and the lagoon. These might represent fish reared in especially favorable stream sites, but also might represent fish reared in upstream portions of the lagoon, where growth rates tend to be lower.

Pattern of Utilization. Yearling steelhead entered the lagoons in large numbers beginning in April, but some entered as soon as rains began in winter. Many of the yearlings were smolts which passed on through to the ocean, but others chose to remain in the lagoon. In 1986 several thousand smolt-sized yearlings remained in San Gregorio, Waddell, and probably Pescadero lagoons, even though access to the ocean was possible in July. At both Waddell and San Gregorio lagoons, yearlings even remained after artificial breaching of the sandbars drastically reduced lagoon water levels. In 1985 early closure (by 1 May) of the sandbar trapped numerous smolted steelhead at Pescadero lagoon.

Young-of-the-year steelhead are present in stream channels inundated by the lagoons in summer and also migrate down into the lagoons. At Waddell Creek lagoon large numbers of juvenile fish were still entering the lagoon in July 1986. The larger number of fish present in the lagoons in 1986 was partly due to higher streamflows, which allowed juvenile fish to move down to the lagoon throughout much of the early summer. In drier years streamflows would quickly decline and restrict passage; in addition, lower streamflows might stimulate less downstream migration.

Steelhead used almost all habitats in San Gregorio, Pescadero, and Waddell lagoons, but larger fish tended to be associated with deeper areas. During periods of low water, such as after sandbar breaches at Waddell and San Gregorio lagoons, larger steelhead were often confined to deeper holes, such as near the bridge abutments. The attraction to the bridges may involve more than just depth, since at Pescadero lagoon schools of steelhead congregated in the shade of the bridge, even though the site is no deeper than much of the embayment upstream.

At Pescadero lagoon schools of steelhead entered the deeper channels of Butano Marsh to feed, despite large diurnal oxygen variation near the dense pondweed of the channels. In 1985 and 1986 steelhead were present early in the summer in North Marsh, after having entered through the culvert (1985) and during the storm overflow into the marsh (1986). The fish had grown to over 300 mm SL on the incredibly abundant invertebrates in the flooded marsh by early summer, but high mid-summer temperatures and low oxygen levels apparently killed any steelhead present.

Early sandbar closure commonly traps some downmigrating adult steelhead. In 1985 the sandbar at Pescadero was closed by 1 May, and 11 adult steelhead were captured by seine or gillnet sampling in June through August. All adults caught were extremely emaciated, and their stomachs were mostly empty. Based upon their condition in midsummer, it is likely that many trapped adults do not survive until the natural fall/winter sandbar breach. In 1987 early sandbar closure also trapped large numbers of adults at Pescadero Creek lagoon.

After heavy winter storms the open estuaries are usually very turbid (secchi depths of 0.1 - 0.5 meters) and probably do not provide very good feeding areas for steelhead. It appears that most of the steelhead raised during the summer in the lagoons enter the ocean in winter, rather than waiting until the normal spring smolting period. Within one month of sandbar breaching in late fall of 1985 most of the steelhead in San Gregorio, Pescadero, and Waddell lagoons had taken on at least partial smolt coloration. However, in mild winters, with reduced inflow of turbid water and sediment, lagoon conditions probably remain good for survival and growth. Large numbers of lagoon-reared steelhead were still present in Waddell Creek lagoon in March of 1988 and 1990. Scale analysis from fish collected in March of 1990 showed relatively poor growth from summer 1989, when water quality was generally poor (Figures 41 and 42), but excellent growth in late winter; most of their size was due to winter growth.

In December of 1985 two steelhead smolts full of Neomysis were collected in Pomponio Creek lagoon, confirming the creek as a steelhead stream. It appears that even tiny lagoons, grossly unsuitable for summer rearing, can contribute to the maintenance of steelhead populations by providing feeding areas during winter or during spring smolt outmigration.

Conditions Required for Lagoon Survival and Growth. In general, growth and survival of steelhead in the lagoons was good when the lagoons were open to full tidal mixing. Growth and survival were also good after lagoons had converted to unstratified (freshwater) conditions, which resulted in lower water temperatures and higher bottom dissolved oxygen levels. Survival and growth were poor when salinity was stratified, which resulted in high water temperatures and poor bottom dissolved oxygen levels.

Fish grew rapidly in the freshwater lagoons in 1985 (Figures 43, 47, and 50), and young-of-the-year fish quickly caught up to the yearling fish in size (fish length-frequency distribution was unimodal by August). By the end of the year fish in Pescadero and San Gregorio lagoons averaged over 150 mm long (SL). Fish in Waddell Creek lagoon were slightly smaller, possibly because of much higher densities in Waddell lagoon.

At Pescadero Creek lagoon in 1986 the fish grew extremely fast in the main embayment in June and July (Figure 45), while the sandbar was fully open. Food was extremely abundant; clouds of Neomysis were present, and the bottom was thick with Corophium. By the end of June steelhead already averaged nearly 130 mm long (SL), and by the end of July they averaged 150 mm long (SL). After sandbar closure, however, water temperatures increased (Figure 8) and bottom dissolved oxygen levels dropped (Figure 9). The fish showed little growth in August and September (Figure 45), while the lagoon was converting to freshwater. By late September the lagoon had finally destratified for salinity (Figure 7B), temperatures had dropped (Figure 8) and dissolved oxygen levels had recovered, except for the very deepest parts of the lagoon (Figure 9). Steelhead growth was again good in October and November (Figure 45).

Fish in the upper arms (site 18B and upstream) of Pescadero Creek lagoon in 1986 showed a different growth pattern in the early summer compared to those in the well-mixed main embayment. The upper arms were shallow, stratified for salinity and static; bottom water temperatures were high, dissolved oxygen levels were low and invertebrates were scarce. While main embayment fish averaged 130 mm long (SL) by the end of June, those in the arms averaged only 80 mm. The major differences in fish size in early summer 1986 in Pescadero Lagoon had little to do with fish age, but were primarily the result of how soon the fish moved down into the food-rich embayment.

At San Gregorio Creek lagoon in 1986 fish sizes averaged much less than in 1985 (Figure 49). In mid October average size was only about 110 mm long (SL). Part of the reduction may have been due to slightly higher densities than in 1985, but the major reason for the reduction in growth rates was the multiple breachings of the sandbar throughout the summer. The breaching greatly reduced lagoon depth and maintained salinity stratification (Figure 23), resulting in periodic high water temperatures (Figure 24) and low bottom dissolved oxygen levels (Figure 26). High water temperatures and poor food availability resulted in little fish growth in summer (Figure 48). Because of the much smaller fish size in 1986 ocean survival was probably substantially reduced and the potential contribution of the lagoon to the adult steelhead run was probably cut by at least half.

At Waddell Creek lagoon in 1986 fish size was also greatly reduced compared to 1985 by sandbar breaching (Figure 52). Several artificial breaches, and possibly one natural breach, resulted in lower water levels and higher temperatures for much of the summer. The lagoon also went through a severe episode of anoxia, due to kelp, which washed in with the tide after a sandbar breach. Most of the invertebrates in the lagoon were killed. However, it appears that most of the fish remained in the lagoon, even though only the surface waters were oxygenated (Figure 35). Because of the lack of substantial growth, yearling and young-of-the-year fish retained different size modes (Figure 51), with young-of-year fish averaging only about 95 mm long (SL) and yearlings only about 140 mm long (SL) by mid October. They had grown only about 20-25 mm since early July.

In 1987 and 1988 Waddell Creek lagoon converted to freshwater (Figure 37), and steelhead growth was very good in 1988 (Figure 52). No fish sampling took place in 1987, but growth and survival were presumably very good in that year also.

Pescadero Creek lagoon in 1987 and 1988 and San Gregorio Creek lagoon in 1987, 1988, and 1989 remained shallow and stratified for salinity, temperature and dissolved oxygen (Figures 10-15 and 27-34). Fish sampling in June 1987 (Table 3) at Pescadero Creek lagoon showed low steelhead abundance and poor growth, but no fall sampling was done to determine over-summer survival and growth. In 1988 Pescadero Creek lagoon was sampled in August and again in November. Steelhead were collected in rather low abundance in August and showed relatively poor growth (Figure 46), equivalent to that of the stratified 1986 San Gregorio and Waddell creek lagoons (Figures 48 and 51). However, intensive sampling in November produced only 5 steelhead in 13 seine hauls. Apparently very few steelhead survived the poor late summer conditions in Pescadero Creek lagoon in 1988, and it is likely that survival was very poor in 1987 also. December 1988 sampling of the very shallow lagoon at San Gregorio Creek captured only 12 steelhead, 10 of which were under the Highway 1 bridge. The lagoon population was probably less than 50 steelhead, although the fish were relatively large (Figure 49). Rearing success was probably similarly poor in San Gregorio Creek lagoon in 1987 and 1989.

In 1989 late sandbar closure and low steamflows at Pescadero Creek lagoon probably would have resulted in a stratified saline and warm lagoon all summer. However, breaching of the sandbar for bridge construction kept the main embayment cool and well mixed for most of the summer (Figures 16-18). Food was abundant and steelhead grew well in 1989 (Figure 46), although numbers were probably low compared to 1985 or 1986.

MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

These results from four different lagoons and from very dry, below average, and relatively wet runoff years suggest that two primary efforts are required to improve the management of Pescadero, San Gregorio and Waddell creek lagoons and other similar coastal lagoons: maintenance of quality and quantity of inflows; and regulation of artificial sandbar breaching and construction.

Freshwater Inflow Requirements

Freshwater inflow into the lagoon after bar formation is important in determining depth, salinity, temperature, and dissolved oxygen patterns in the lagoon. Streamflow diversions can therefore greatly alter the quality of the lagoon as a habitat for invertebrates and fish. Summer streamflow in San Gregorio and Pescadero creeks is heavily utilized by streamside urban and agricultural interests. Diversions are already sufficient to delay or prevent freshwater conversion and severely impact lagoon conditions in drought years (Table 2), and applications for additional diversion are expected. Waddell Creek presently suffers relatively less diversion impact, because the lagoon is smaller, but the lagoon is still frequently impacted. In light of our findings that the lagoons provide a crucial percentage of watershed rearing habitat for steelhead, careful consideration should be given by management agencies (Department of Fish and Game, Water Resources Control Board, Corps of Engineers, etc.) to the impact of water diversion upon lagoons. The Department of Parks and Recreation should protest water appropriations which threaten lagoon habitat.

The amount of water necessary to convert the lagoons to freshwater will vary substantially with the amount of salt water impounded at the time of sandbar formation, the depth and volume of the lagoon, and the size and configuration of the sandbar, but can be loosely estimated using 1985 - 1988 observations (Table 2). Lagoons can contain in excess of 60 percent sea water at the time of sandbar formation (Table 2), so bypass flows should be set high enough to convert a lagoon of 66 percent sea water to full freshwater conditions. At Pescadero Creek lagoon the amount of gaged streamflow required to achieve 1 % conversion of salt water to fresh water varied from 7 to 50 acre feet (Table 2), with 4 of the 7 values ranging from 11 to 13 acre feet. It appears that 12 acre feet per percent fresh water conversion might be sufficient. Assuming 66 % salt water, this would require 6 cfs for 66 days or 12 cfs for 33 days to convert Pescadero Creek lagoon to freshwater, once the lagoon has closed.

San Gregorio Creek lagoon is smaller, and required less inflow for conversion (Table 2). The amount of water required for each 1 % conversion to fresh water varied from 1.4 to 30.7 acre feet, with 4 of the 5 values at 4.5 or less. If 4.5 acre feet is assumed to be sufficient and 66 % salt water at the time of sandbar formation is planned for, 2.25 cfs for 66 days or 4.5 cfs for 33 days would be necessary to convert the lagoon to freshwater and produce good steelhead rearing conditions. Since salt water loss due to sandbar seepage is greater if the lagoon water levels are higher, and since poor rearing conditions exist during the freshwater conversion period, the higher rate (4.5 cfs) for the shorter period (33 days) is greatly preferable. However, more inflow might be required, as none of the data used for the estimate are from years when full freshwater conversion occurred. In addition, it should be noted that present lagoon inflows at the time of sandbar formation (Table 1) rarely meet these requirements, due to present heavy diversion rates.

No data for the comparison of inflows and freshwater conversion is available for Waddell Creek lagoon, but a very rough estimate of flows needed for freshwater conversion can be made based upon relative sizes of Waddell, Pescadero, and San Gregorio creek lagoons. It appears that Waddell lagoon might need flows of as much as 1.5-2 cfs for 33 days if it was very salty at the time of sandbar formation.

Because inflows necessary for salt water conversion probably vary from year to year, periodic sampling of the lagoon for salinity conditions should be a part of the bypass flow regulation procedure. Once the lagoon converts to freshwater (approximately 1 PPT), unstratified conditions the inflows can be reduced. Since the deepest part of each lagoon is normally at the Highway 1 bridge, a representative lagoon salinity profile can be easily determined from the bridge in 10 - 15 minutes. The profile should be determined in deepest portion of the channel. A salinity meter with a cable at least 75 feet long would be necessary at San Gregorio Creek lagoon, as the bridge sidewalk is normally 45 feet above the the water surface near the south abutment (the usual location of the deepest portion of the channel).

In addition to inflows for freshwater conversion, the lagoons need sufficient inflow throughout the summer to maintain their depth. The amount of inflows would depend upon the desired depth, as lagoons with higher water levels would have greater sandbar seepage loss. The amount of inflows would also depend upon the sandbar configuration, as width and length of the bar would also affect seepage rates. Size of the lagoon and the extent and type of adjacent land flooded would have to be determined for various water stages at the lagoons in order to arrive at a desired lagoon height and required inflow. Very rough estimates, based upon lagoon heights and gaged flows in 1985 - 1988, show that Pescadero Creek lagoon can probably maintain Highway 1 staff gage water heights of 4.5 - 5.0 feet at flows of 2.5 - 3.0 cfs at the USGS gage. At San Gregorio Creek lagoon Highway 1 staff gage heights of 3.0 feet probably require flows past the USGS gage of 1.5 - 2.0 cfs. At Waddell Creek lagoon Highway 1 staff gage heights of 4.0 feet probably require flows of 0.5 - 0.75 cfs. (Note: the staff gages on the bridges were arbitrarily placed, and are not referenced to mean sea level). As shown by the summer-long declines in lagoon levels in 1987 - 1989 (Figures 10 and 27), present stream diversions are already too great to allow sufficient lagoon inflows to maintain summer depth in drought years.

Quality of Inflows

Agricultural (and potentially urban) waste waters can have drastic, although difficult to document, impacts upon these sensitive and important habitats. Levees or other barriers to contaminated runoff from surrounding lands should be evaluated.

Sandbar Breaching

Summertime breaching of sandbars severely alters habitat conditions in the lagoons. For steelhead trout these alterations adversely affect fish abundance and growth rates. Despite these adverse effects and despite the Department of Fish and Game, Coastal Commission, and Corps of Engineers permits required for breaching, legal and illegal lagoon openings regularly occur. At Pescadero lagoon the bar is opened to reduce flooding of artichoke fields. At San Gregorio lagoon the bar is apparently opened to protect water diversions and to provide beach access. At Waddell lagoon occasional artificial sandbar breaching apparently occurs, but the reasons and persons responsible are not known. The sandbars have also apparently been breached in early winter by fishermen wanting to allow steelhead access to the lagoon; in the absence of sufficient flows to allow easy upstream migration, the only benefit is to fishermen and poachers.

At Pescadero lagoon the longterm solution to the conflict should be the purchase of lands threatened by normal lagoon water levels. Levees might also be used to protect some lands subject to very high lagoon water levels. Acquisition and levees may also reduce the threat to the lagoon/marshland system from pesticides in runoff.

At San Gregorio lagoon the perceived conflict between lagoon water levels and water diverters might be relieved by situating the diversion intakes at the lagoon surface. In the upper end of the lagoon, surface waters were fresh, even when bottom waters were mildly brackish; if the bar remained in place the entire lagoon would be freshwater by mid summer. A minor conflict between recreational access and lagoon water levels can be expected whenever the lagoon shifts towards the north bluff. This can be avoided by creating a sand ramp along the cliff <u>prior to</u> sandbar closure.

In severe drought years, when there is no prospect of inflows sufficient to convert the lagoons to freshwater conditions, maintaining an open sandbar might improve conditions for steelhead at some lagoons. However, the lagoon must have a large, wide embayment to produce good tidal exchange and mouth scour, so that substantial rearing habitat is created and frequent breaching is not required. Among the lagoons studied, only Pescadero Creek lagoon might benefit. Pescadero Creek lagoon did manage to rear fast-growing steelhead in the open lagoon in 1989, although the numbers of fish were probably not large. However, the open lagoon in 1989 may have reduced tidewater goby numbers and resulted in the drying of most of North Marsh, so careful consideration should be given to the effects on the entire ecosystem before action is taken.

At San Gregorio and Waddell creek lagoons the sandbar partially forms and then the long, meandering outlet slowly closes as the sandbar widens. Full sandbar closure and conversion of the lagoons to freshwater might be speeded by artificially closing off the narrow outlet. Such an action would require careful study, because of the Department of Fish and Game, Coastal Commission and Corps of Engineers permits that would be required. Such action should not be undertaken until late June, so as not to interfere with steelhead smolt outmigration.

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Table 1. Approximate dates of sandbar closure and streamflow (USGS 1987, 1988A, 1988B, 1989, 1990) at time of closure for Pescadero, San Gregorio and Waddell creeks. (Lagoon inflows are approximate, as exact dates of closure are not known and diversions exist downstream of the USGS gages on Pescadero and San Gregorio creeks. Butano Creek also enters Pescadero lagoon.)

Year	Date of Sandbar Closure	Streamflow at Gage at Time of Closure
<u>Pescadero</u>		
1985	late April	> 9.0 cfs
1986	mid July	4.5 - 5.5
1987	late March	> 8.5
1988	late March or early April	> 4.0
	May 21-23	2.6-2.9
1989	mid May	2.8-3.5
<u>San Gregorio</u>		
1985	early July	1.5
1986	mid June	> 7.0
1987	late May	1.5-2.5
1988	late March or early April	3 - 4
	mid May	2.0
1989	mid July	< 0.5
<u>Waddell</u>		
1985	early July	
1986	early July	
1987	mid-late May	
1988	early April	
	mid May	
1989	early June? late June	

Table 2. Amount of lagoon conversion from salt water (35 ppt) to freshwater (1 ppt) compared to gaged flows (USGS 1987, 1988A, 1988B, 1989) for Pescadero and San Gregorio creeks for 1985 - 1988.
(Gaged flows are approximations of lagoon inflow, as diversions exist downstream of the USGS gages on both streams, and Butano Creek enters downstream of the gage on Pescadero Creek.)

Year	Dates	% Salt Water Begin	% Salt Water End	Percent Conversion	Mean Flow	AcreFeet/ % Conversion
Pescadero						
1985	16 May - 1 June	25	7	18	7.7	246/18= 13
	1 June - 16 June	7	0.5	6.5	6.4	208/6.5= 32
1986	23 July - 24 Aug	49	28	21	3.9	250/21= 12
	24 Aug - 27 Sept	28	4	24	4.3	292/24= 12
1987	10 Apr - 8 June	42	32	10	4.2	495/10= 50
	8 June - 3 Aug	32	16	16	1.5	168/16= 11
1988	24 May - 27 June	61	36	24	2.5	170/24= 7
San Gregorio						
1985	19 July - 11 Sept	36	6	30	0.5	53/30= 1.8
	11 Sept - 27 Oct	6	1.5	4.5	1.5	138/4.5= 30.7
1987	8 June - 11 Aug	43.5	29	11.5	0.4	51/11.5= 4.5
	18 Oct - 30 Oct	23	11	12	2.0	48/12= 4.0
1988	24 May - 1 July	65	49	16	0.3	22/16= 1.4

Table 3. Fish species collected in Pescadero, San Gregorio, Waddell, and Pomponio creek lagoon/estuary. Abundances rated from 1 (rare) to 5 (abundant). O below date indicates sandbar was open.

	Pescadero Creek Lagoon														
	1984		1985			1986				1987		1988		1989	
Species	Jl	Dc	My	JJ	Nv	Ap	JJ	Sp	Nv	Fb	Jn	Ag	Nv	My	Sp
		O			O	O	O			O				O	
Stickleback	3	2	4	3	5	2	5	4	4	2	3	5	2	3	2
Tidewater Goby	4	3	3	4	2	2	2	2	2	3	2	3	3	1	1
Steelhead	2		3	4	4	2	5	5	5	2	2	2	1	3	3
Staghorn Sculpin	5	2	5	5	1	2	2	3		1	5	3	1	1	2
Prickly Sculpin	2	1	2	2	2	3	3	2	2	2	2	2	2		1
Starry Flounder	2	3	3	3	2	3	3	3	2	2	2	2	1	2	2
Shiner Perch	3	2	2	1		1	2	1			2	5	5		2
Pacific Herring	1		1	1	1					1	1	5			
Topsmelt	2				3		2			1		2	2		4
Striped Bass				1		2						1	2	2	
Yellowfin Goby		1		1								2	1		
Coho			1												
Bay Pipefish	1														
English Sole							3								
N. Anchovy							2								
Cabezon							2								1
Brown Rockfish							1								
Kelp Greenling							1								
Pacific Sanddab							1								
Saddleback Gunnel							1								
Walleye Surfperch							1								
White Perch					1										

Table 3 (continued)

	San Gregorio Creek					Waddell Creek								
	1985		1986		1988	1985			1986			1988		
Species	Jn	ND	JJ	Ot	Dc	Jn	Nv	Dc	Ap	JJ	Ot	Mr	My	Ot
	O	O	O				O	O				O	O	
Stickleback	3	5	5	5	5	2	3	1		3	5	1	3	5
Tidewater Goby	3	3	3	2	3									
Steelhead	3	3	5	5	2	5	5	3	3	5	5	2	4	4
Staghorn Sculpin	5	2	2	1	1	3	1	1	2	1		3	3	
Prickly Sculpin	2	1	2	1	1	3	2	2	1	2	2	1	2	2
Starry Flounder	2	2	2	2	1	2	1	1		2	1	1	1	1
Shiner Perch	2				1									
Pacifc Herring	1													
Topsmelt		2												
Coho									2			2		
Coastrange Sculpin		1												
Penpoint Gunnel										1				
Golden Shiner												2		

Table 3 (Continued)

	Pomponio Creek		
Species	1985 JJ	1985 Dc	1986 JJ
		0	
Stickleback	3	3	5
Steelhead		1	
Staghorn Sculpin	3	1	1
Prickly Sculpin	1	1	2
Starry Flounder	2		

Table 4. Freshwater rearing habitat utilized by adult steelhead collected on Pescadero Creek 1985 - 1989, based upon freshwater growth rates and sizes determined from scales.

Rearing Location	Number of Fish	Percent of Fish
1 year stream	0	0
2 years stream	3	11.1
Undetermined: 1 year stream or lagoon*	5	18.5
1 year stream, plus 1 year lagoon	2	7.4
2 years stream, plus heavy lagoon growth prior to entering ocean	1	3.7
1 year lagoon	16	59.3
Totals	27	100
Fish with substantial lagoon rearing	19-24	70.4-88.9

*Fish with undetermined rearing location showed growth intermediate between that expected for the stream or the lagoon.

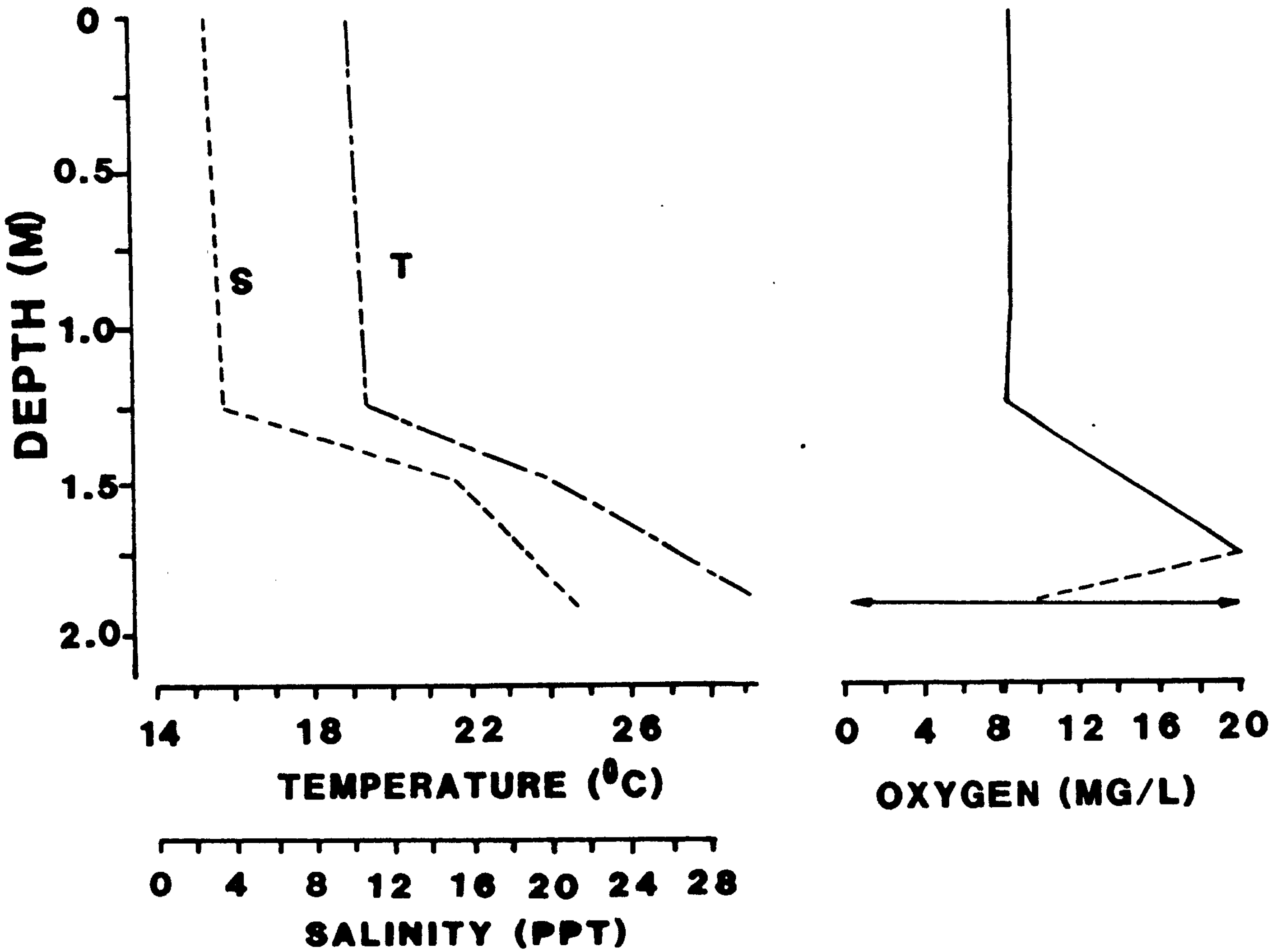

Figure 1. Temperature (T), salinity (S) and dissolved oxygen profiles for Pescadero Creek lagoon (Site 6: mid-embayment) for 31 July 1984, showing: salinity stratifcation and resulting temperature and dissolved oxygen stratification. Dissolved oxygen at the bottom ranged from 0.5 mg/l in morning (11:03) to 20+ mg/l in the evening (19:35).

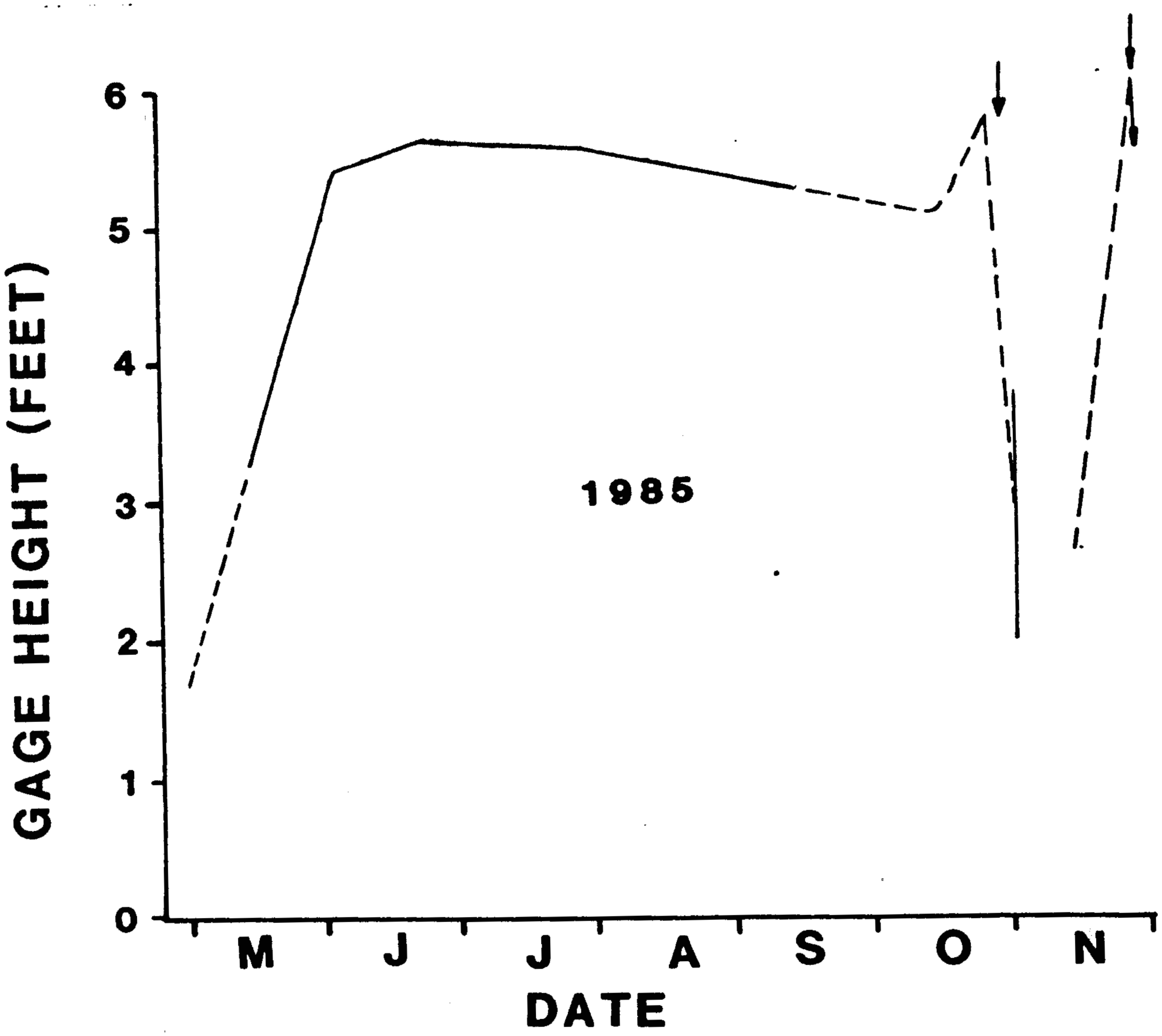

Figure 2. Water levels at Pescadero Creek lagoon in 1985, showing: A) rapid filling of the lagoon after sandbar formation in late April; B) gradual decline in late summer due to low streamflows and sandbar seepage; and C) increase in water level in October due to rain and runoff. The sandbar was artificially breached (arrows) on 31 October and again on 28 November.

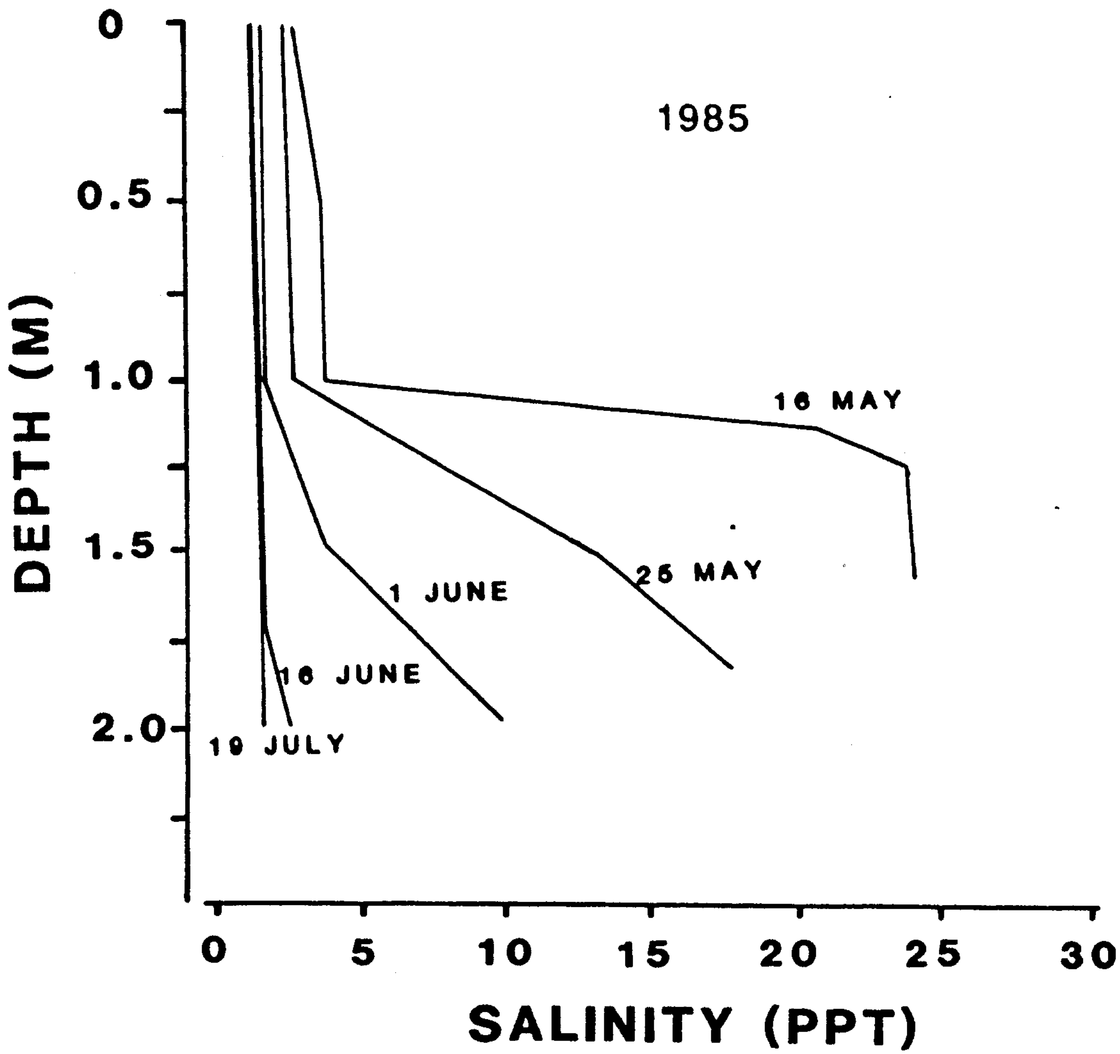

Figure 3. Salinity profiles for Pescadero Creek lagoon (site 2: Highway 1 bridge) in 1985, showing: A) salt water lens on the bottom third of the lagoon on 16 May; and B) gradual elimination of the salt water lens by 19 July due to freshwater inflow and sandbar seepage.

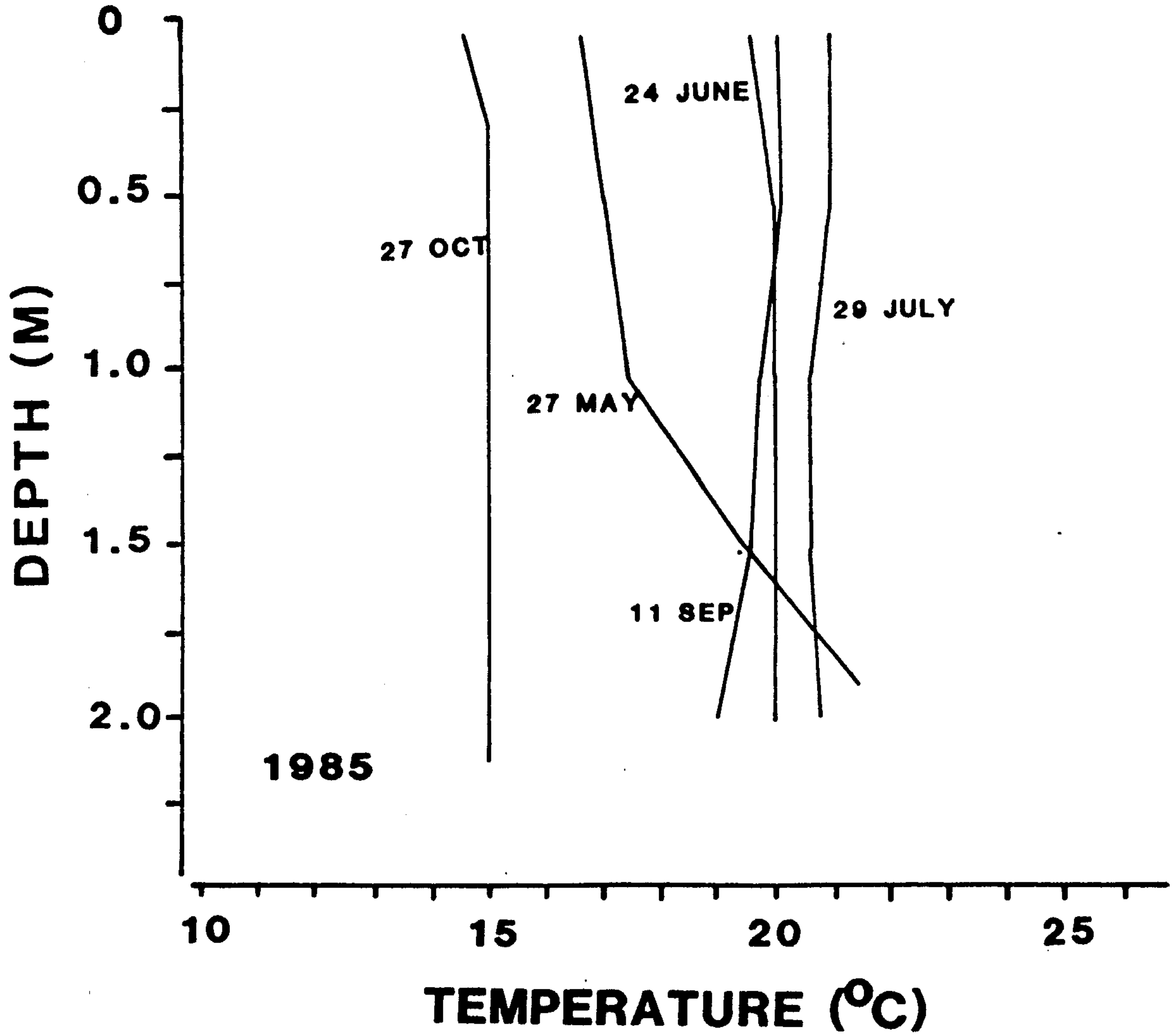

Figure 4. Water temperature profiles for Pescadero Creek lagoon (site 2) for 1985, showing: A) higher temperatures within the salt water lens present on 27 May; and B) lack of temperature stratification after salinity stratification was eliminated in mid June.

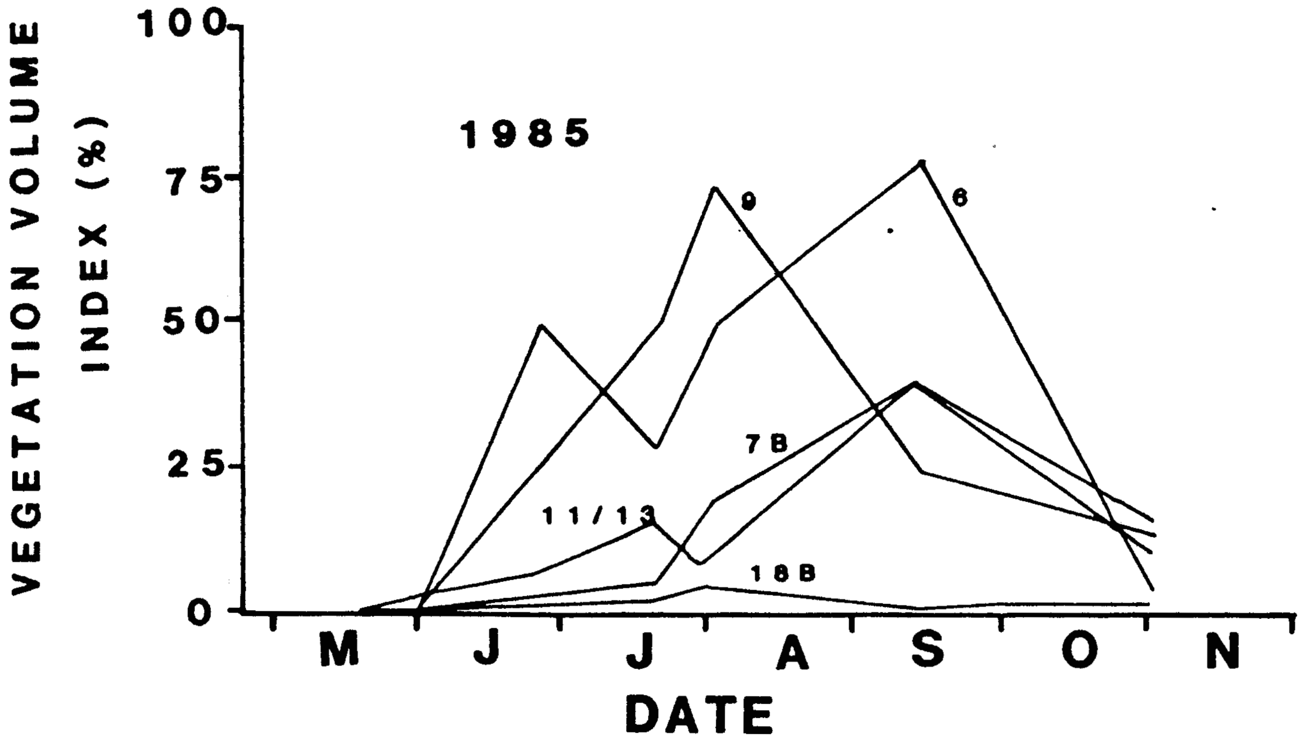

Figure 5. Estimated abundance of pondweed at Pescadero Creek lagoon sites in 1985, showing: A) increase in abundance into August and September; and B) decline with cooler water temperatures and increased inflow to the lagoon in October.

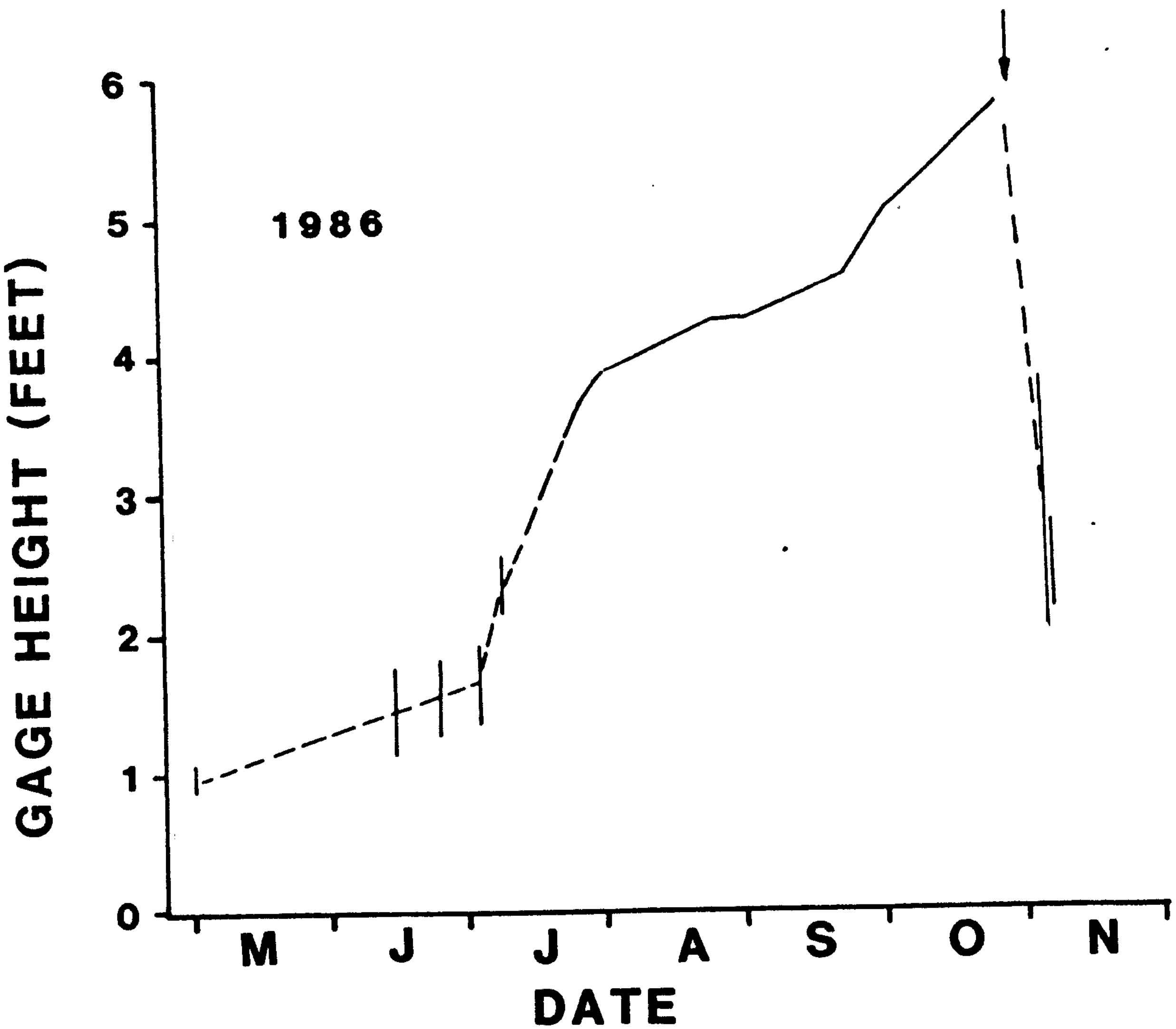

Figure 6. Water levels at Pescadero Creek lagoon in 1986, showing: A) delay in sandbar closure until July and rapid filling of the lagoon for the first 2 weeks after closure; B) much slower increase in August and September; and C) increase with late September and October rains and runoff. The sandbar was artificially breached (arrow) on 31 October.

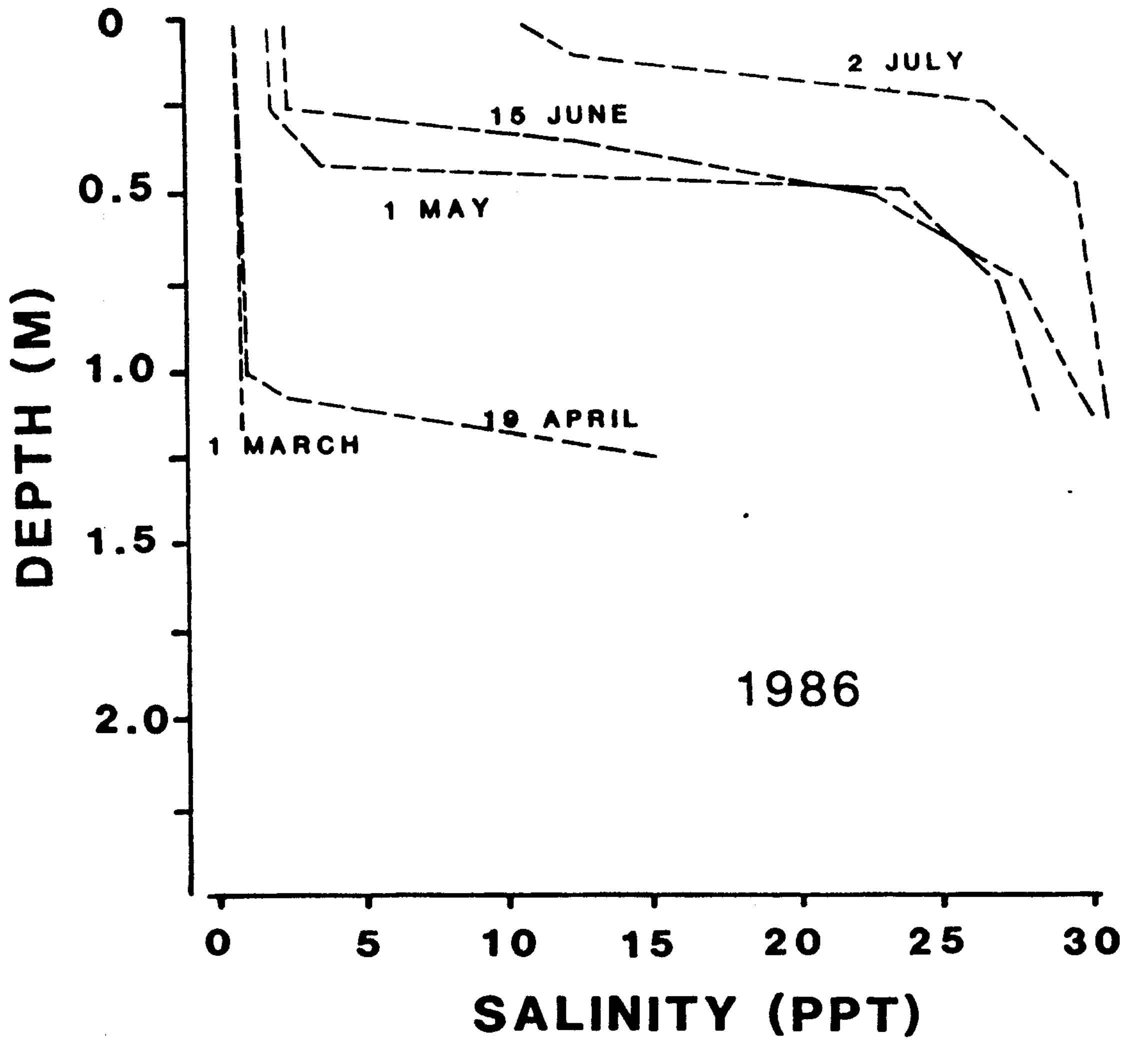

Figure 7A. Salinity profiles for Pescadero Creek lagoon (site 2) prior to sandbar closure in 1986, showing: A) freshwater conditions during heavy winter runoff on 1 March; and B) the gradual development of a thick salt water wedge on the bottom as freshwater inflows declined from 19 April to 2 July.

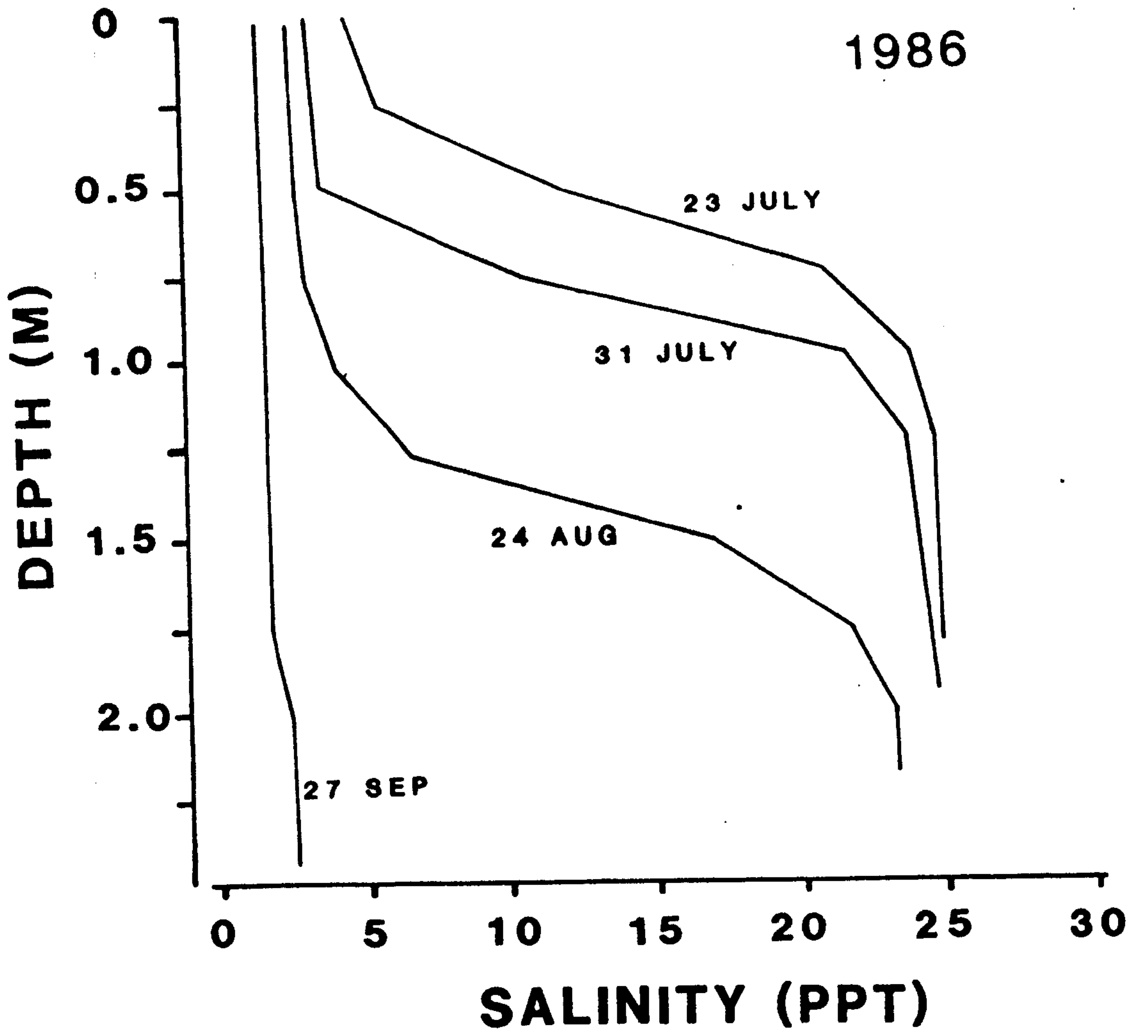

Figure 7B. Salinity profiles for Pescadero Creek lagoon (site 2) after sandbar closure in 1986, showing: A) salt water lens on the bottom two-thirds of the lagoon on 23 July; and B) lens thinning and near-elimination due to freshwater inflow and seepage through the sandbar by 27 September.

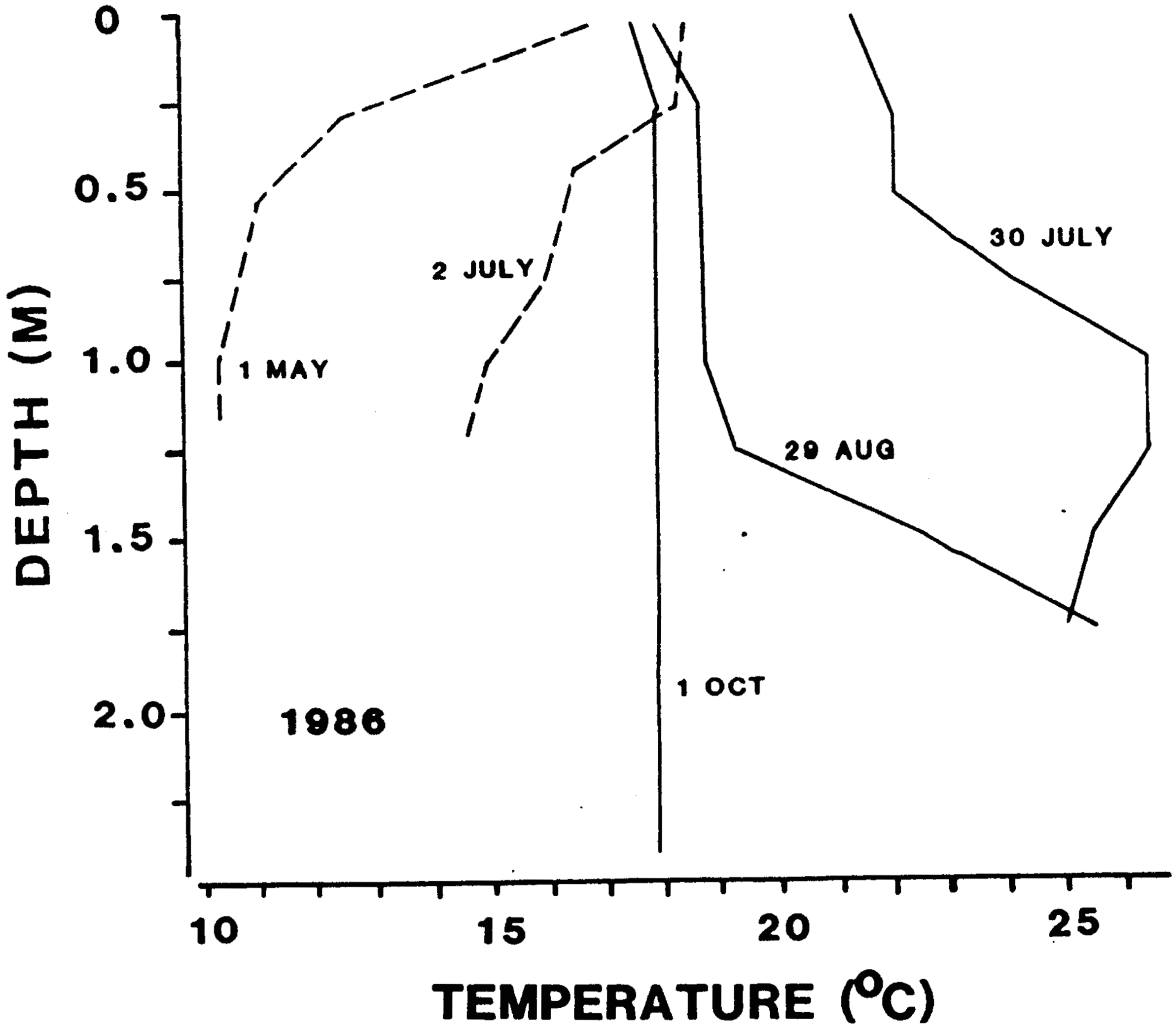

Figure 8. Water temperature profiles for Pescadero Creek lagoon (site 2) for 1986, showing: A) low bottom temperatures compared to surface prior to sandbar formation (1 May and 2 July), due to tidal mixing; B) relatively higher temperatures within the bottom saltwater lens after sandbar formation (30 July and 29 August); C) very high water column temperatures with the thick salt water lens on 30 July; and D) lack of temperature stratification after salinity stratification had been eliminated (1 October).

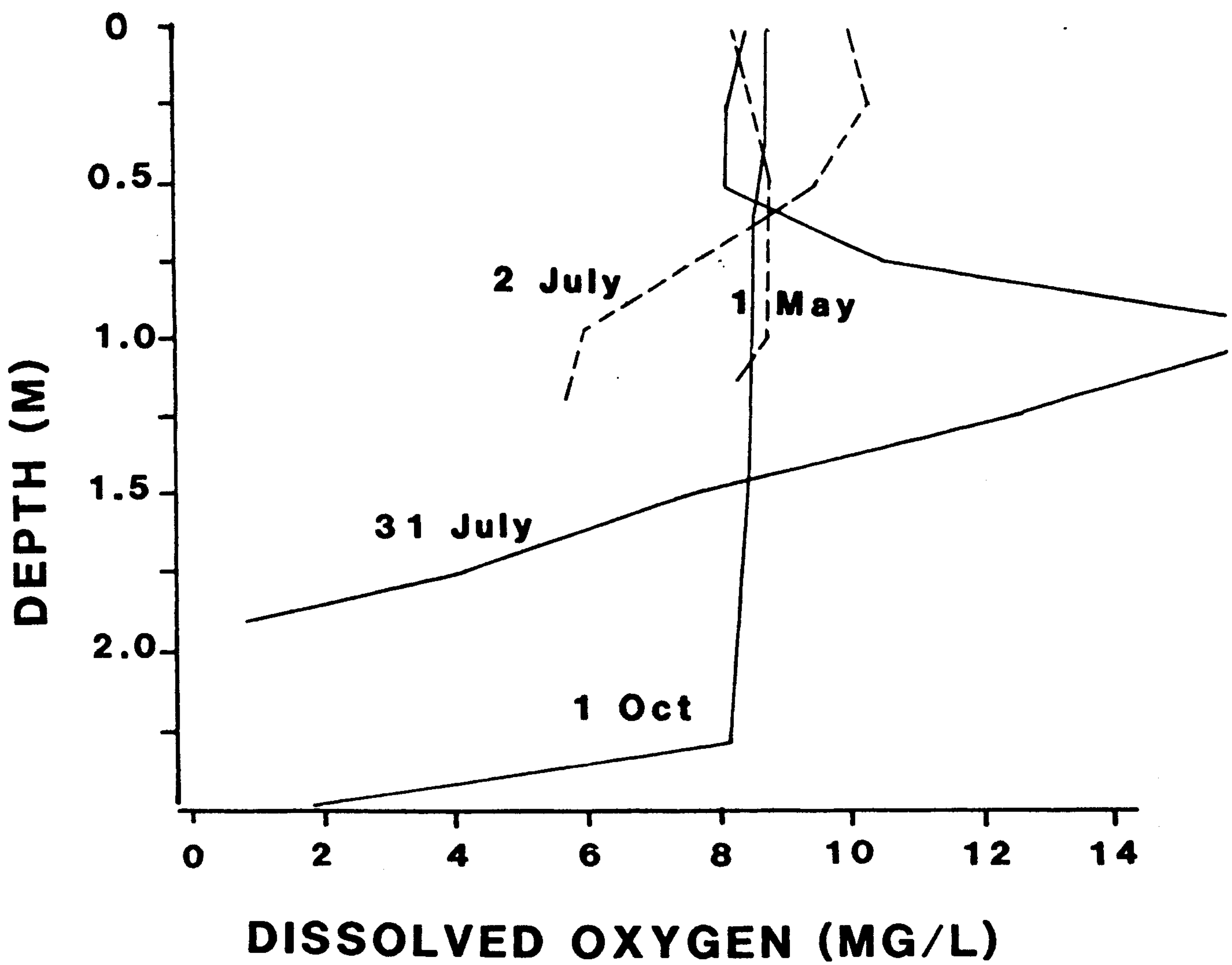

Figure 9. Dissolved oxygen profiles for Pescadero Creek lagoon (site 2) for 1986, showing: A) relatively well-mixed dissolved oxygen levels prior to sandbar formation (1 May and 2 July); and B) supersaturated oxygen at the top of the salt water lens and low bottom dissolved oxygen in the closed lagoon on 31 July.

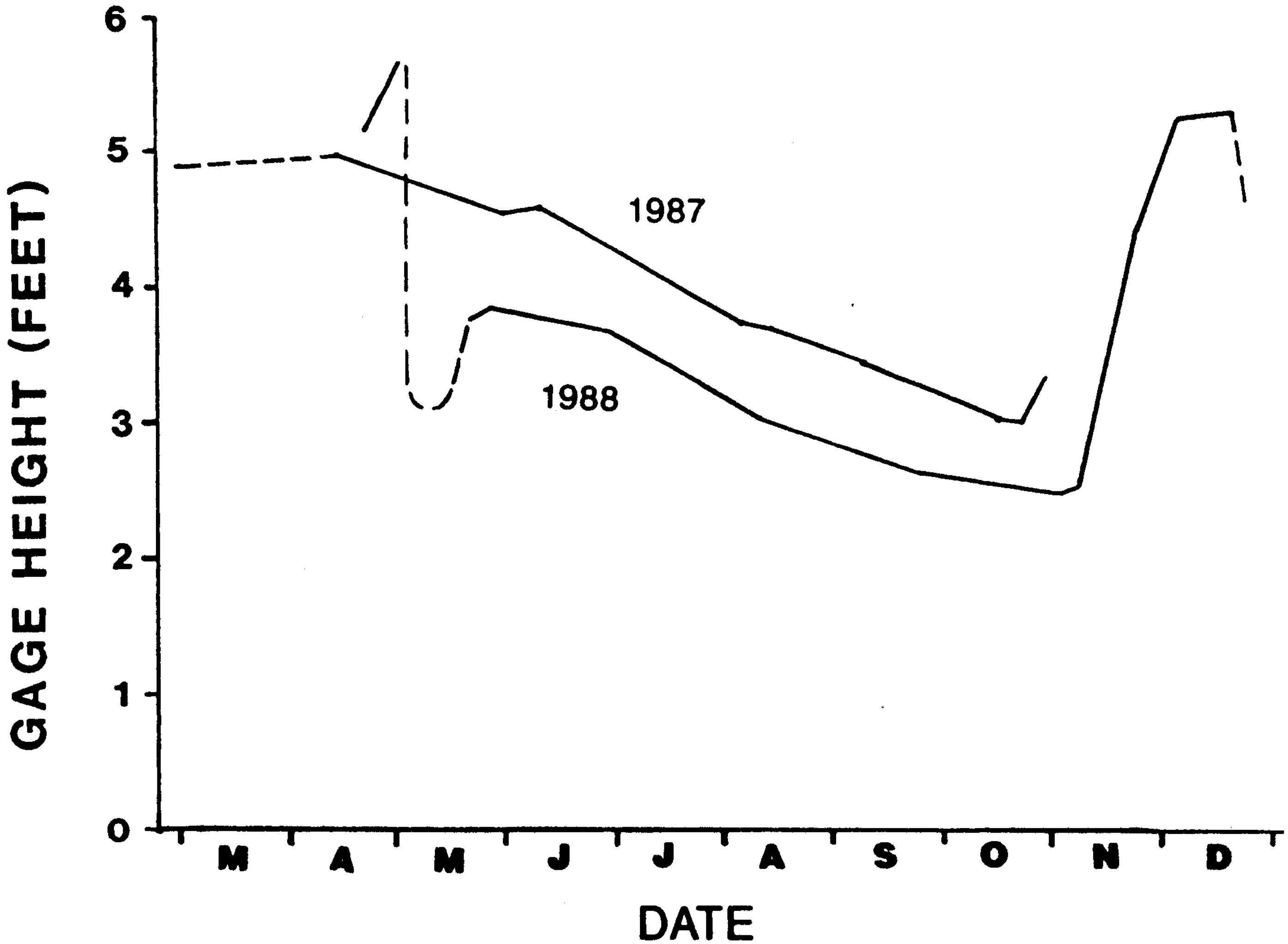

Figure 10. Water levels at Pescadero Creek lagoon in 1987 and 1988, showing: A) early sandbar formation in 1987, followed by gradual decline in lagoon water level due to sandbar seepage, evaporation, and low inflows; and B) breaching of early sandbar by late April storm in 1988, followed by sandbar reformation and gradual decline in lagoon water levels until November rain and runoff.

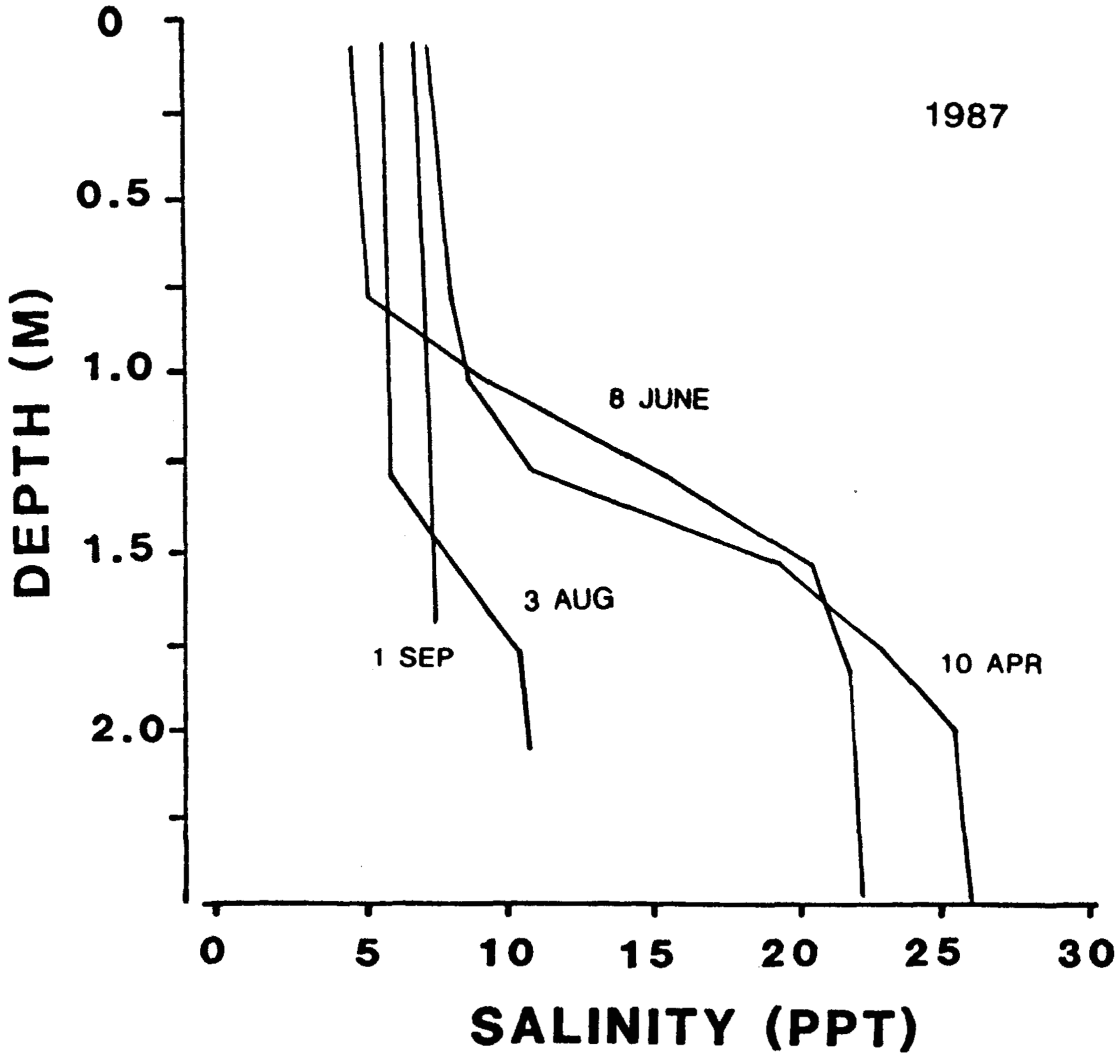

Figure 11. Salinity profiles for Pescadero Creek lagoon (site 2) in 1987, showing: A) saline surface waters and only slight change in salinity from 10 April to 3 August, due to very low inflows; and B) brackish unstratified conditions on 1 September, due to wind mixing in the wide, shallow embayment (wind-sheltered arms of the lagoon remained stratified).

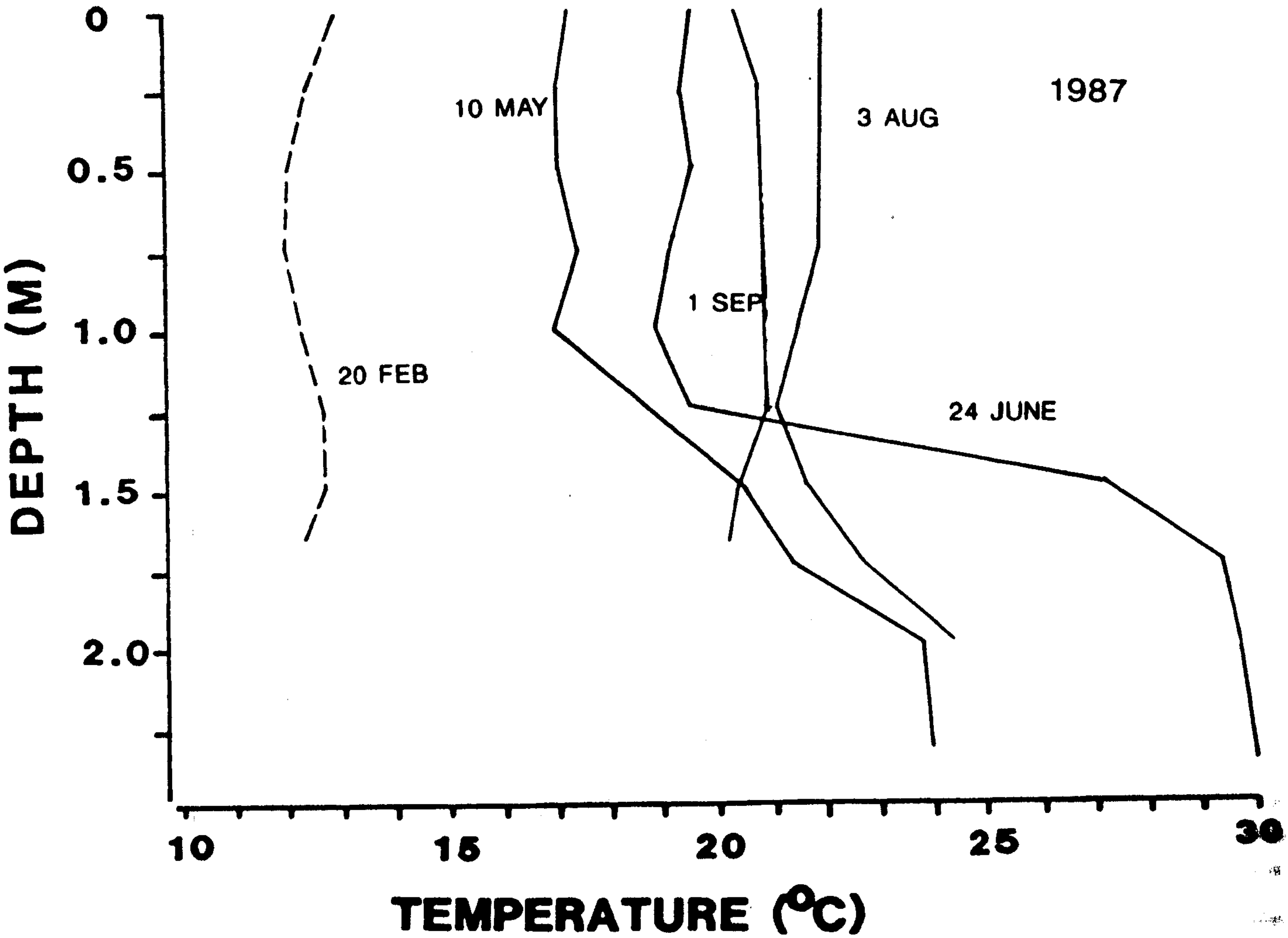

Figure 12. Water temperature profiles for Pescadero Creek lagoon (site 2) for 1987, showing: A) higher water temperatures within the bottom salt water lens on 10 May, 24 June, and 3 August; B) extremely high salt water lens water temperatures on 24 June; and C) lack of temperature stratification on 1 September, when the main embayment no longer showed salinity stratification.

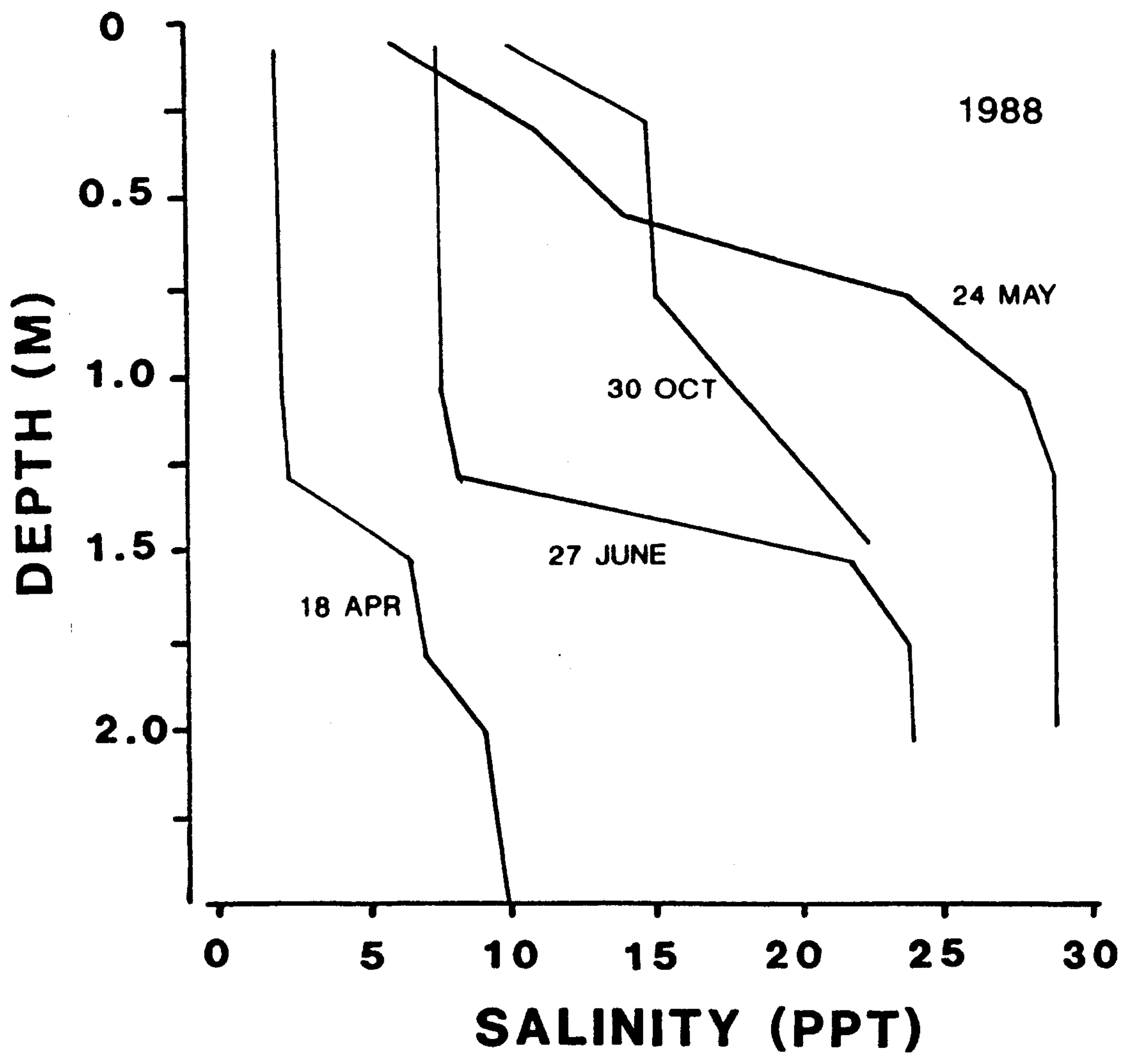

Figure 13. Salinity profiles for Pescadero Creek lagoon (site 2) for 1988, showing: A) relatively low salinities on 18 April prior to 24 April sandbar breaching; B) high salinity levels after sandbar reformed (24 May); C) thinning of the bottom salt water layer between 24 May and 27 June, due to freshwater inflows and sandbar seepage; and D) little change in mean water column salinity between 27 June and 30 October, due to lack of inflows, but less pronounced stratification, due to wind mixing.

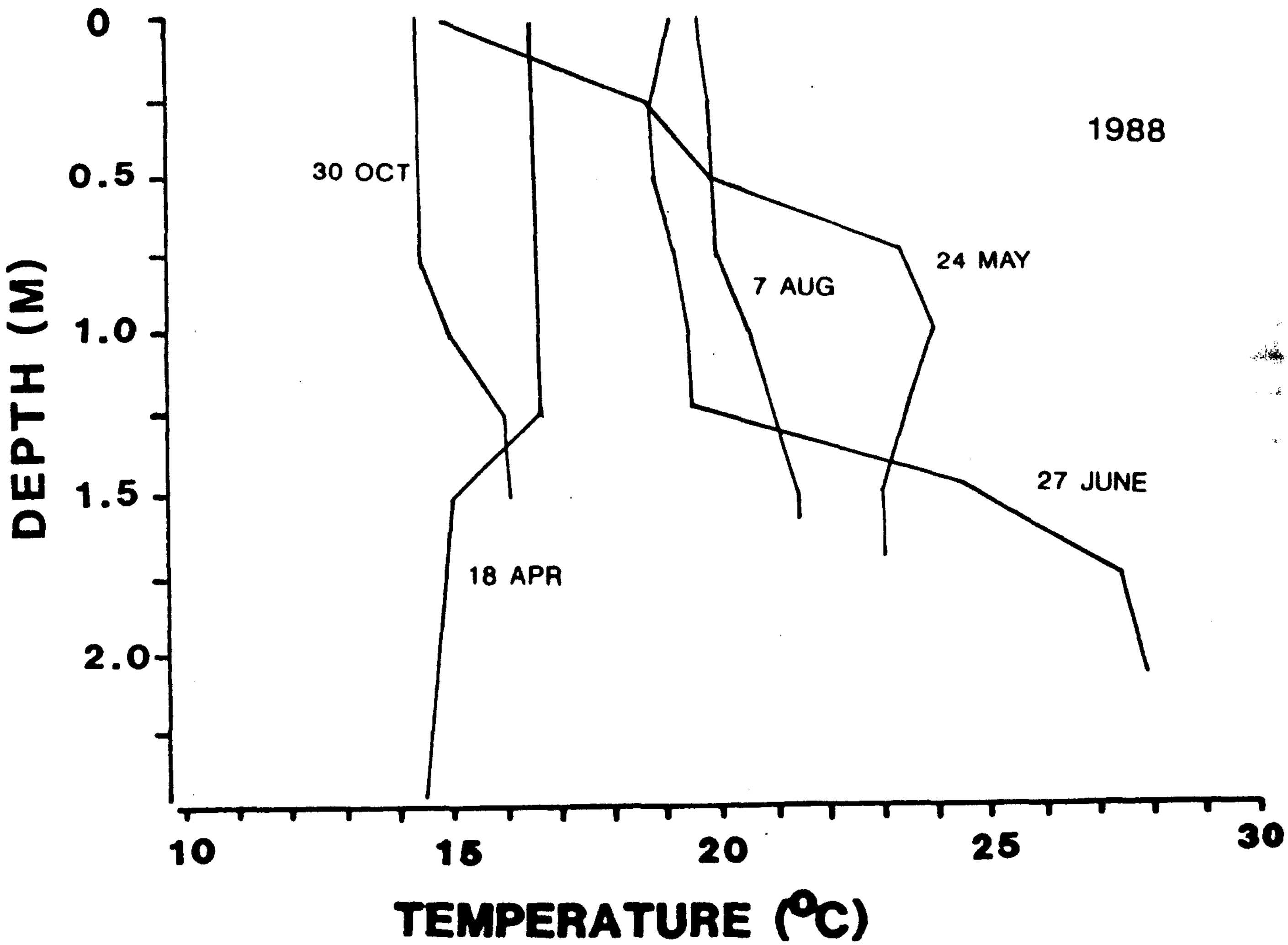

Figure 14. Water temperature profiles for Pescadero Creek lagoon (site 2) for 1988, showing: A) higher water temperatures within the bottom salt water lens for all dates except early spring (18 April); B) extremely high water temperatures within the bottom salt water lens on 27 June; and C) lower salt water lens water temperatures on 7 August, due to several days of overcast and to shading by dense pondweed growth.

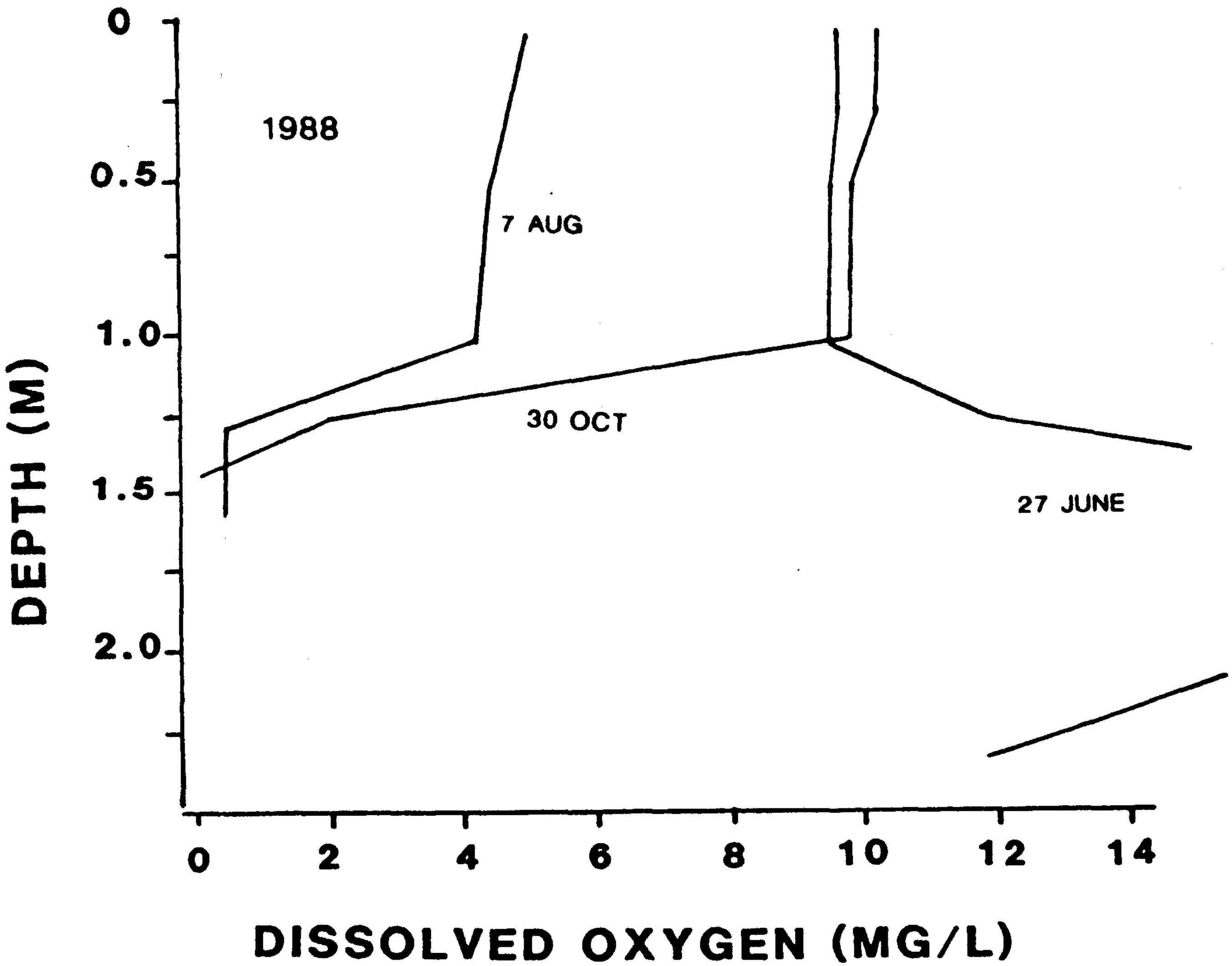

Figure 15. Dissolved oxygen profiles for Pescadero Creek lagoon (site 2) for 1988 showing: A) supersaturated conditions within the bottom salt water lens on 27 June; B) very low dissolved oxygen levels at the bottom of the salt water lens on 7 August and 30 October; and C) low water column dissolved oxygen on 7 August, due to dense pondweed growth and overcast.

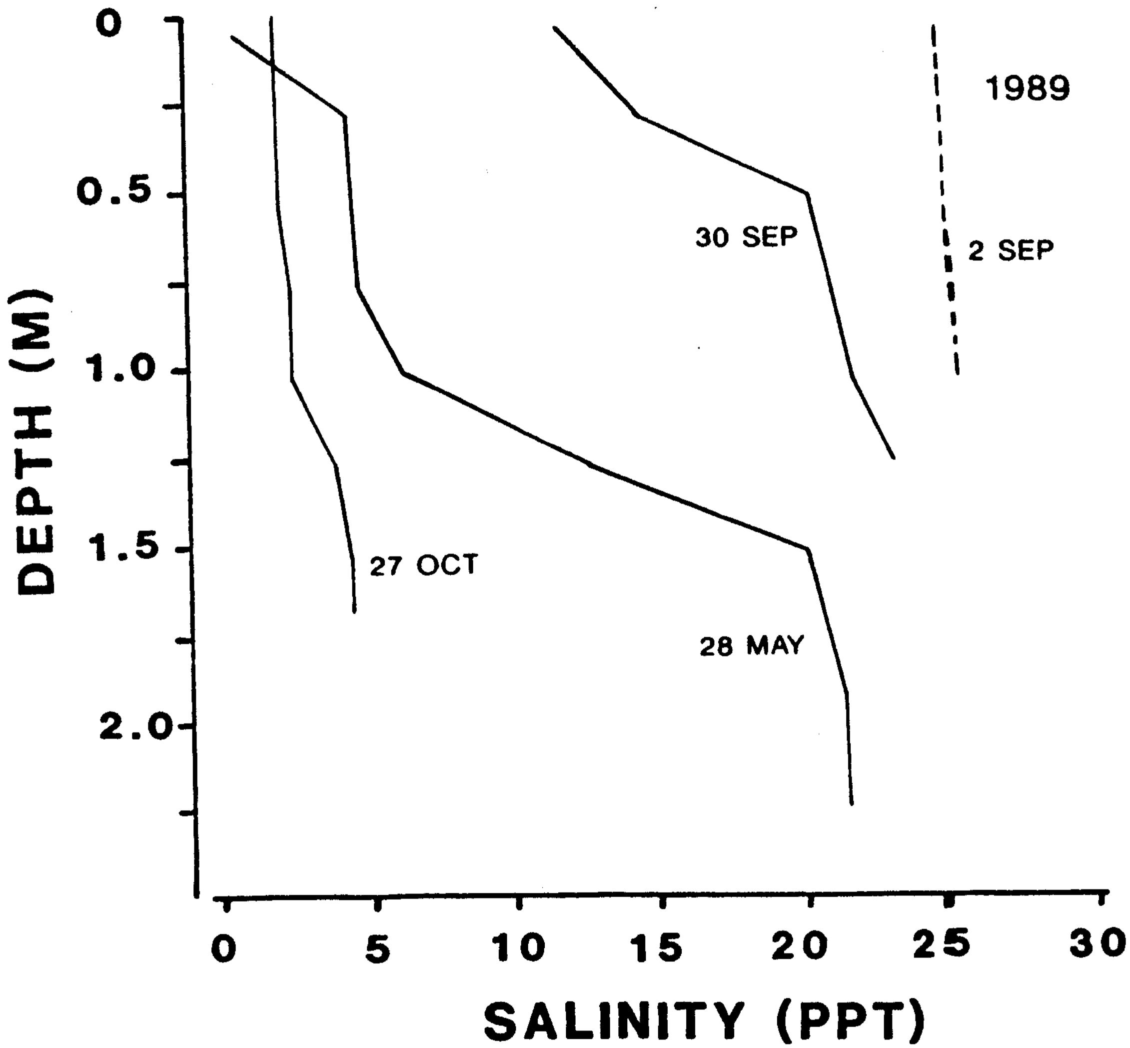

Figure 16. Salinity profiles for Pescadero Creek lagoon (site 2) for 1989, showing: A) pronounced stratification in the closed lagoon on 28 May; B) unstratified conditions in the tidally mixed open lagoon on 2 September; C) restratification of the lagoon after sandbar closure in mid September; and D) near-conversion of the lagoon to freshwater by October runoff following the Loma Prieta earthquake and an early storm.

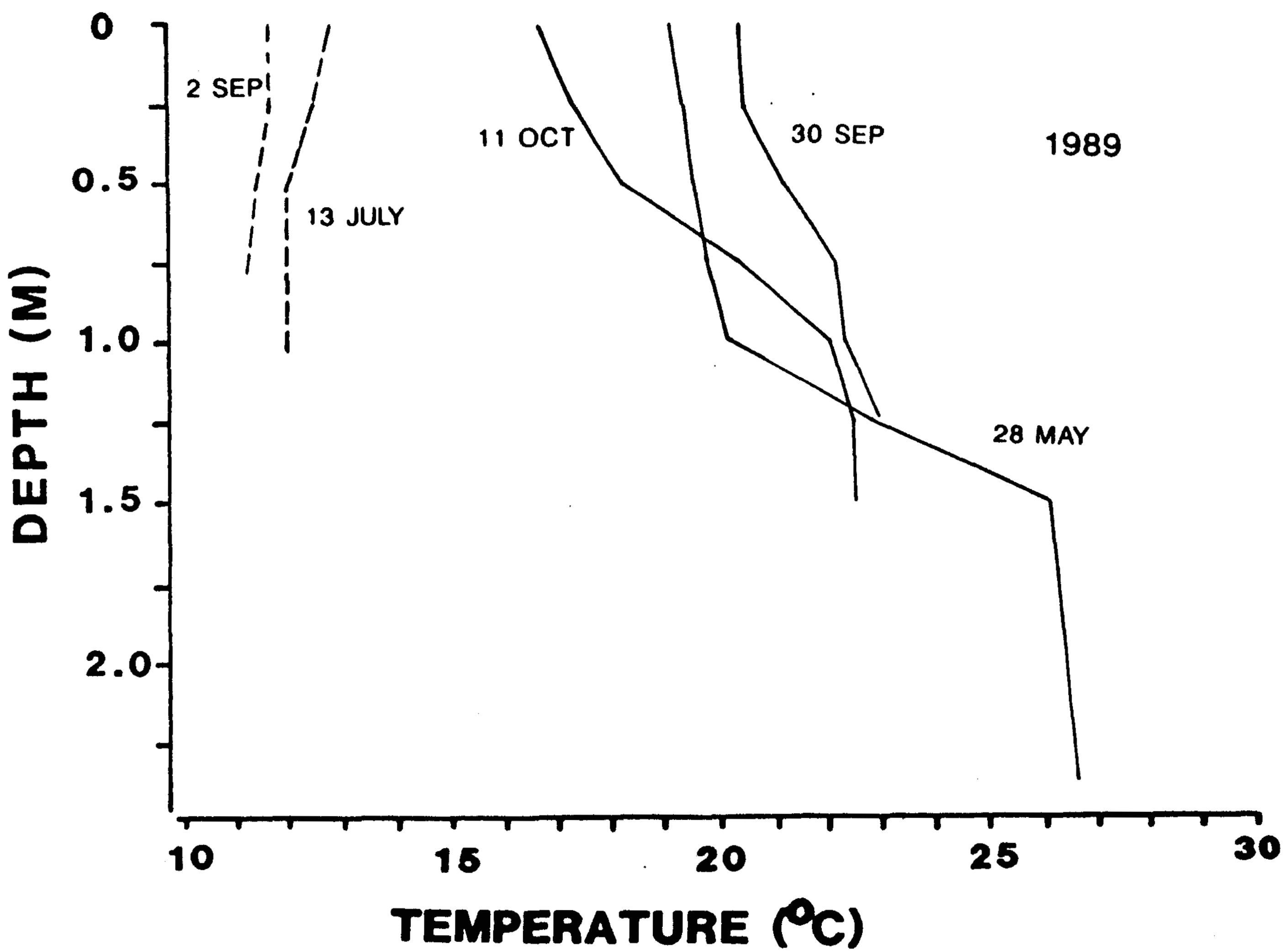

Figure 17. Water temperature profiles for Pescadero Creek lagoon (site 2) for 1989, showing: A) higher water temperatures within the bottom salt water lens of the closed lagoon on 28 May, 30 September, and 11 October; B) very high lens water temperatures on 28 May; and C) very low, unstratified water temperatures in the tidally mixed, open lagoon on 13 July and 2 September.

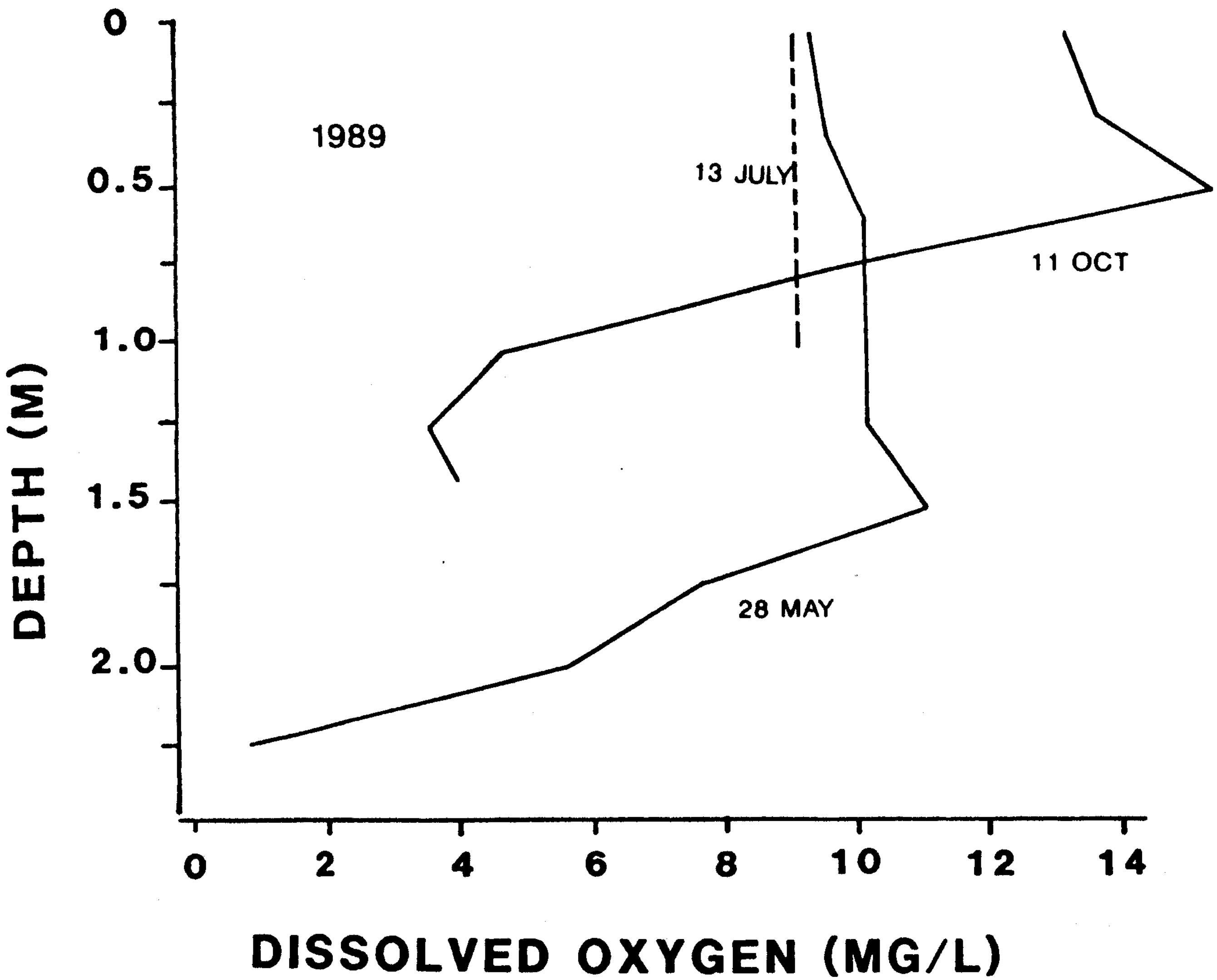

Figure 18. Dissolved oxygen profiles for Pescadero Creek lagoon (site 2) for 1989, showing: A) high, unstratified dissolved oxygen levels in the tidally mixed, open lagoon on 13 July; and B) low dissolved oxygen on the bottom of the salt water lens in the stratified, closed lagoon on both 28 May and 11 October.

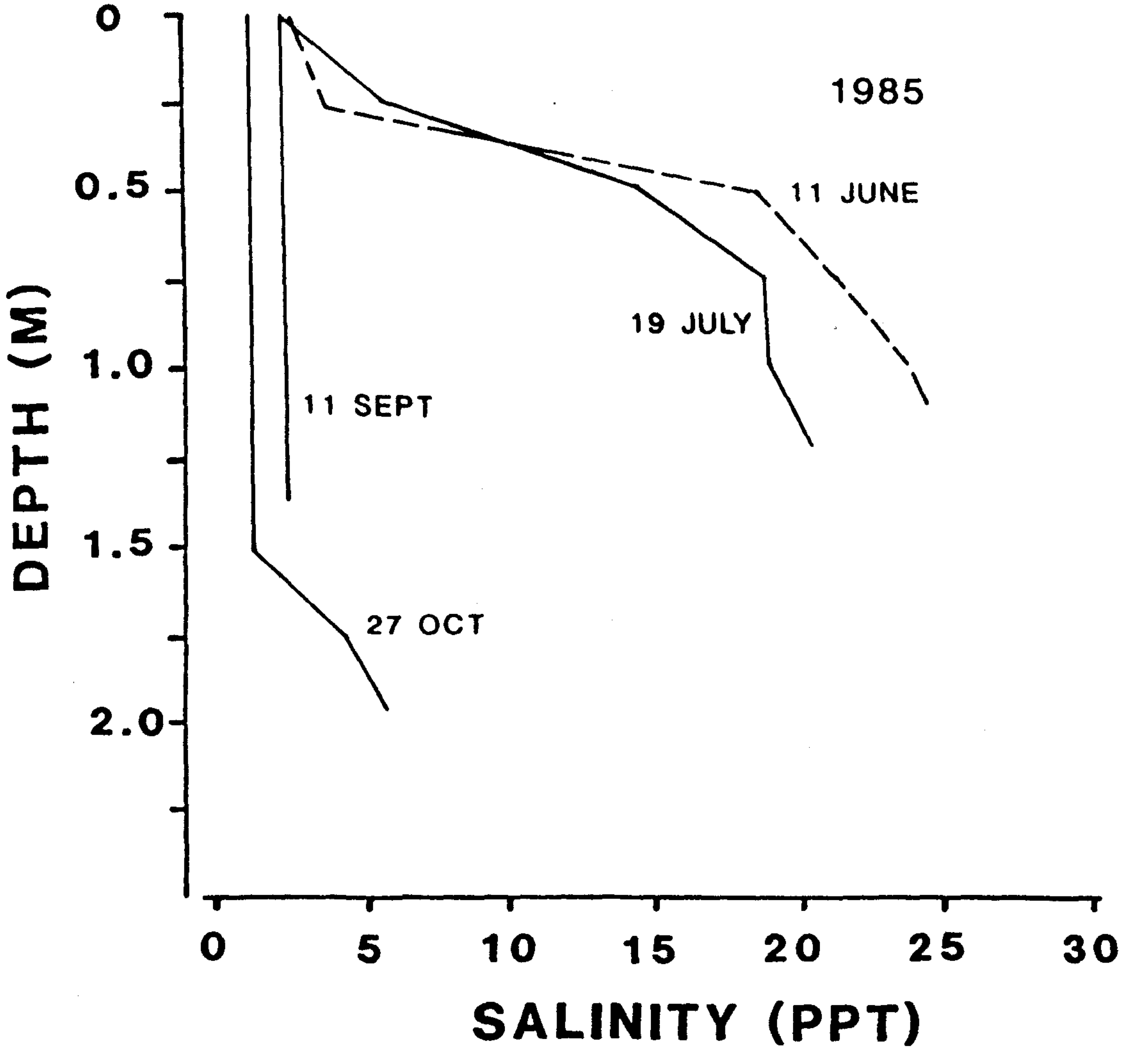

Figure 19. Salinity profiles for San Gregorio Creek lagoon (site 5: Highway 1 bridge) for 1985, showing: A) thick salt water lens on the bottom of the partially closed (11 June) and recently closed (19 July) lagoon; B) unstratified, low salinity conditions on 11 September, due to freshwater inflows, sandbar seepage, and wind mixing; and C) increased depth with fresher surface waters, due to 21 October rain and runoff, and salt water lens on bottom, probably due to tidal sandbar overwash.

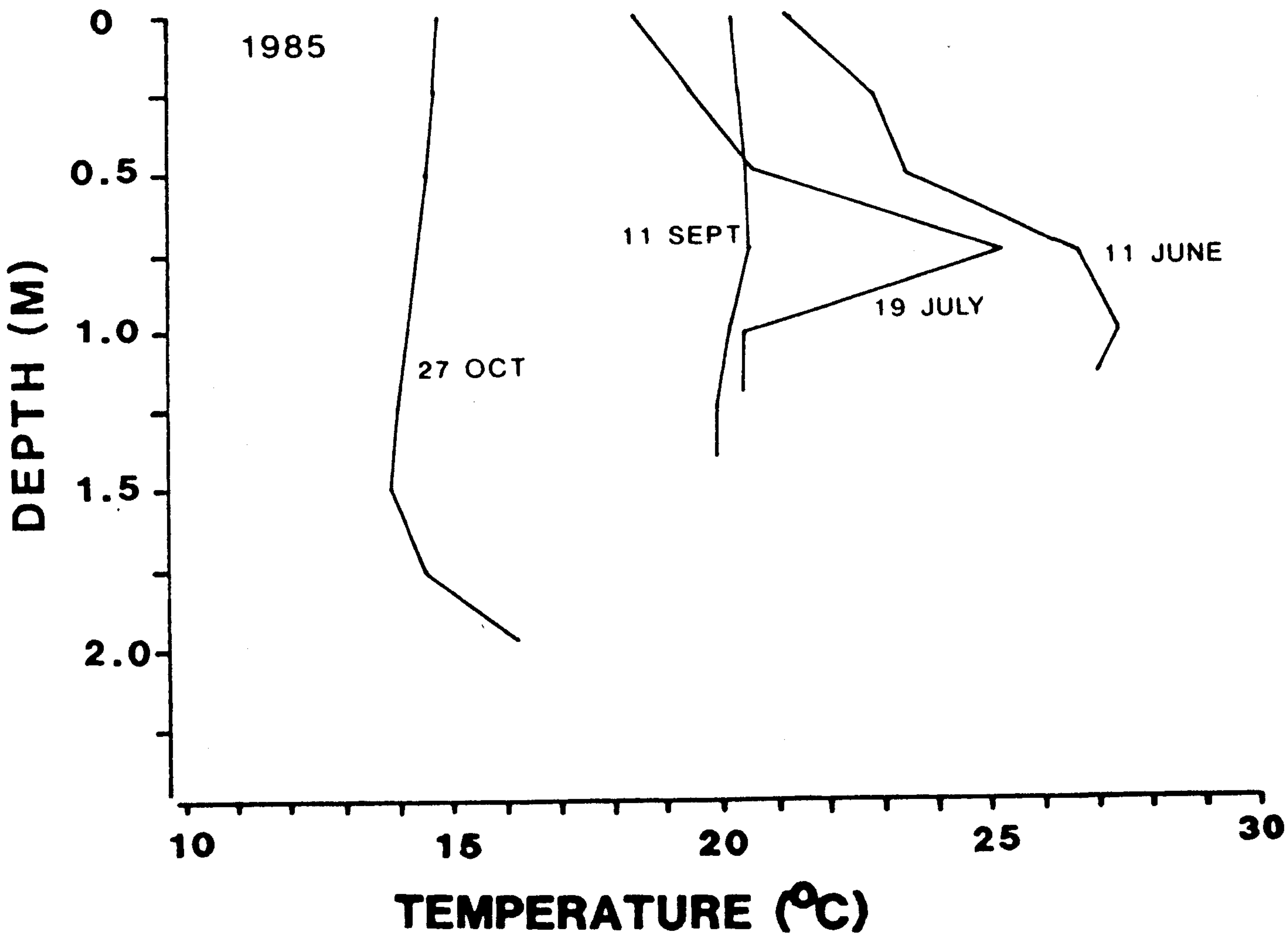

Figure 20. Water temperature profiles for San Gregorio Creek lagoon (site 5) for 1985, showing: A) relatively higher water temperatures within the bottom salt water lens on 11 June, 19 July and 27 October, when the lagoon was stratified for salinity; and B) equalized water temperatures on 11 September, when the lagoon was not stratified for salinity.

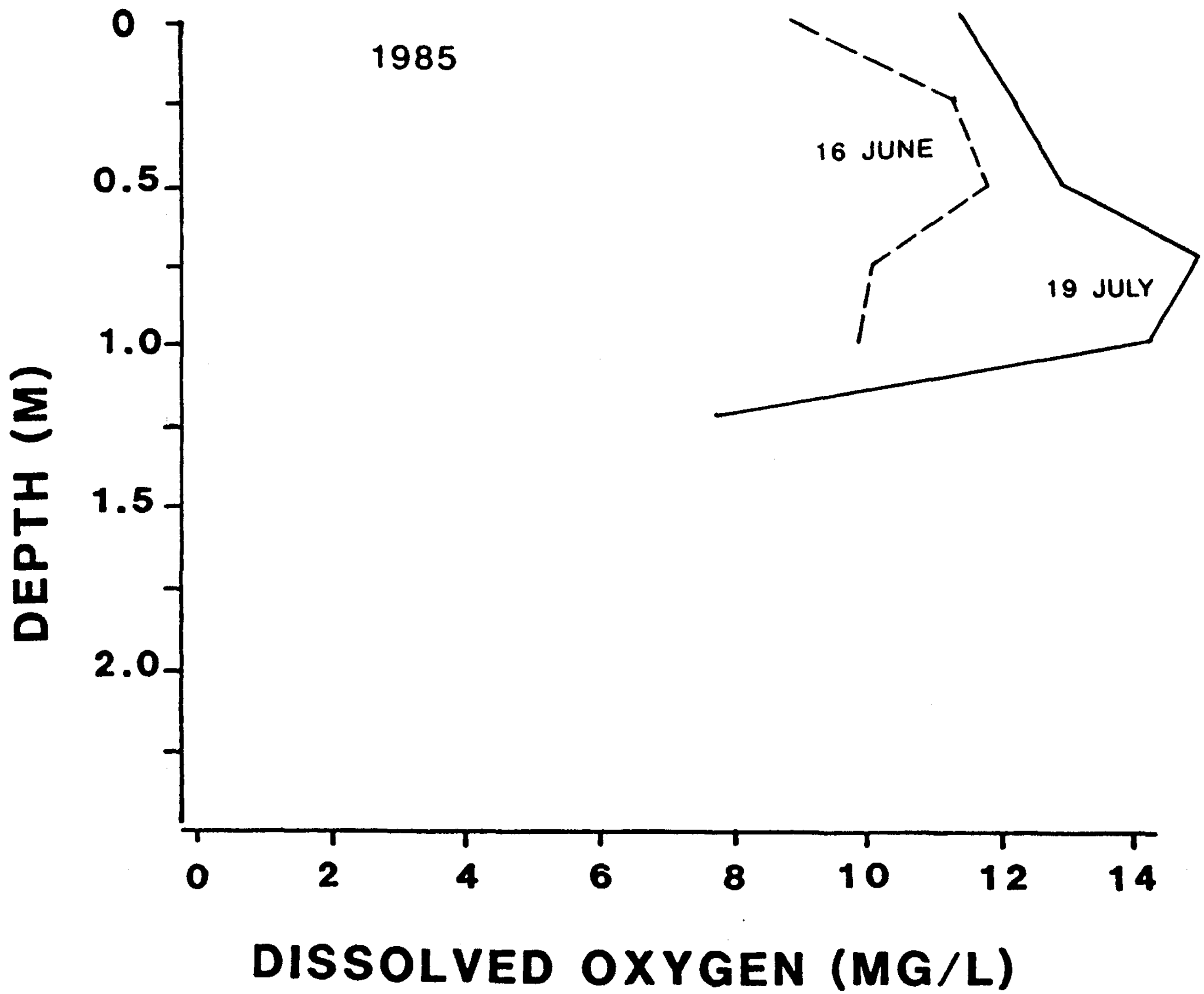

Figure 21. Morning dissolved oxygen profiles for San Gregorio Creek lagoon (site 5) for 1985, showing complex dissolved oxygen stratification within the bottom salt water lens in the partially closed (16 June) and recently closed (19 July) lagoon.

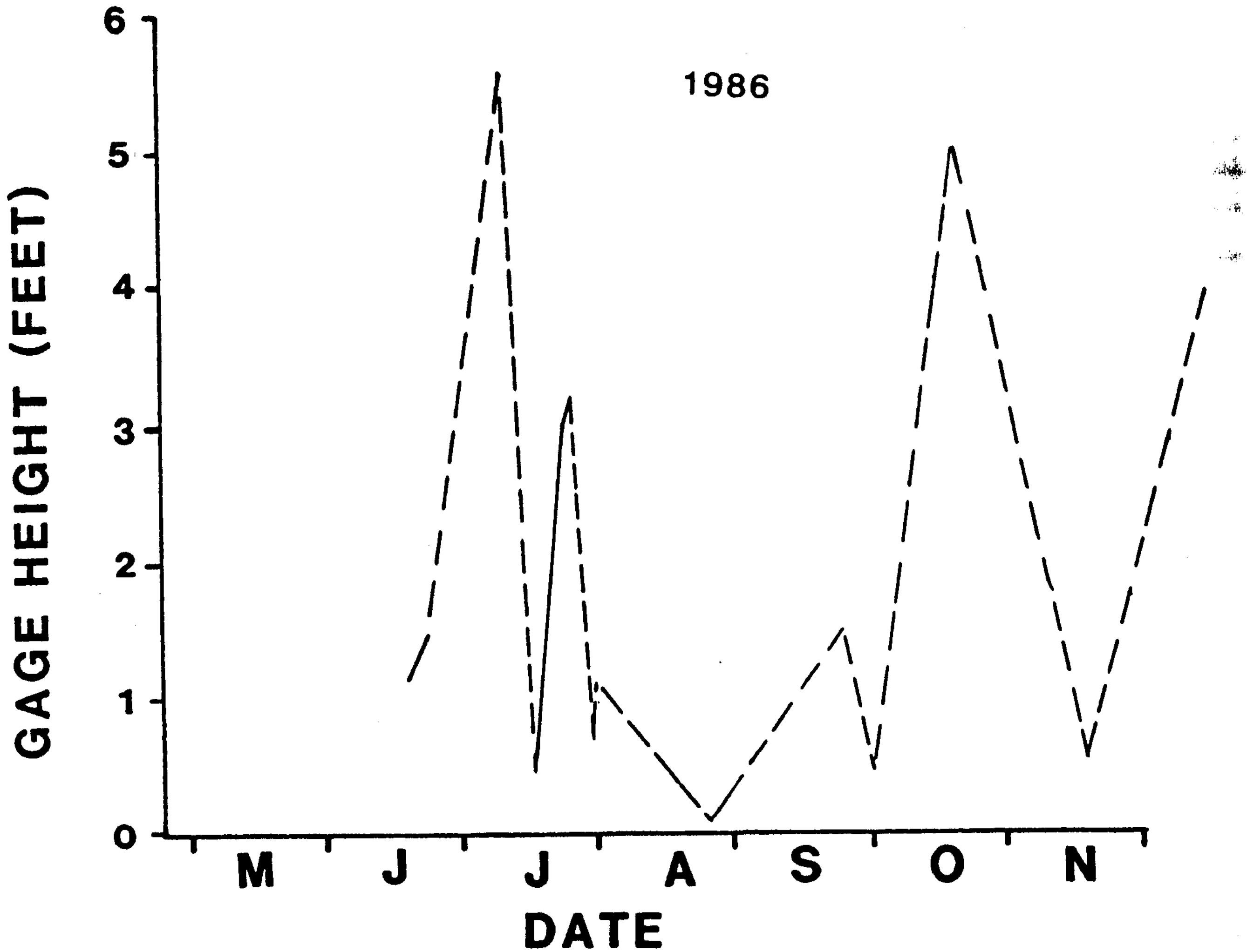

Figure 22. Water levels for San Gregorio Creek lagoon for 1986, showing showing wildly fluctuating levels, due to repeated sandbar formation and breaching.

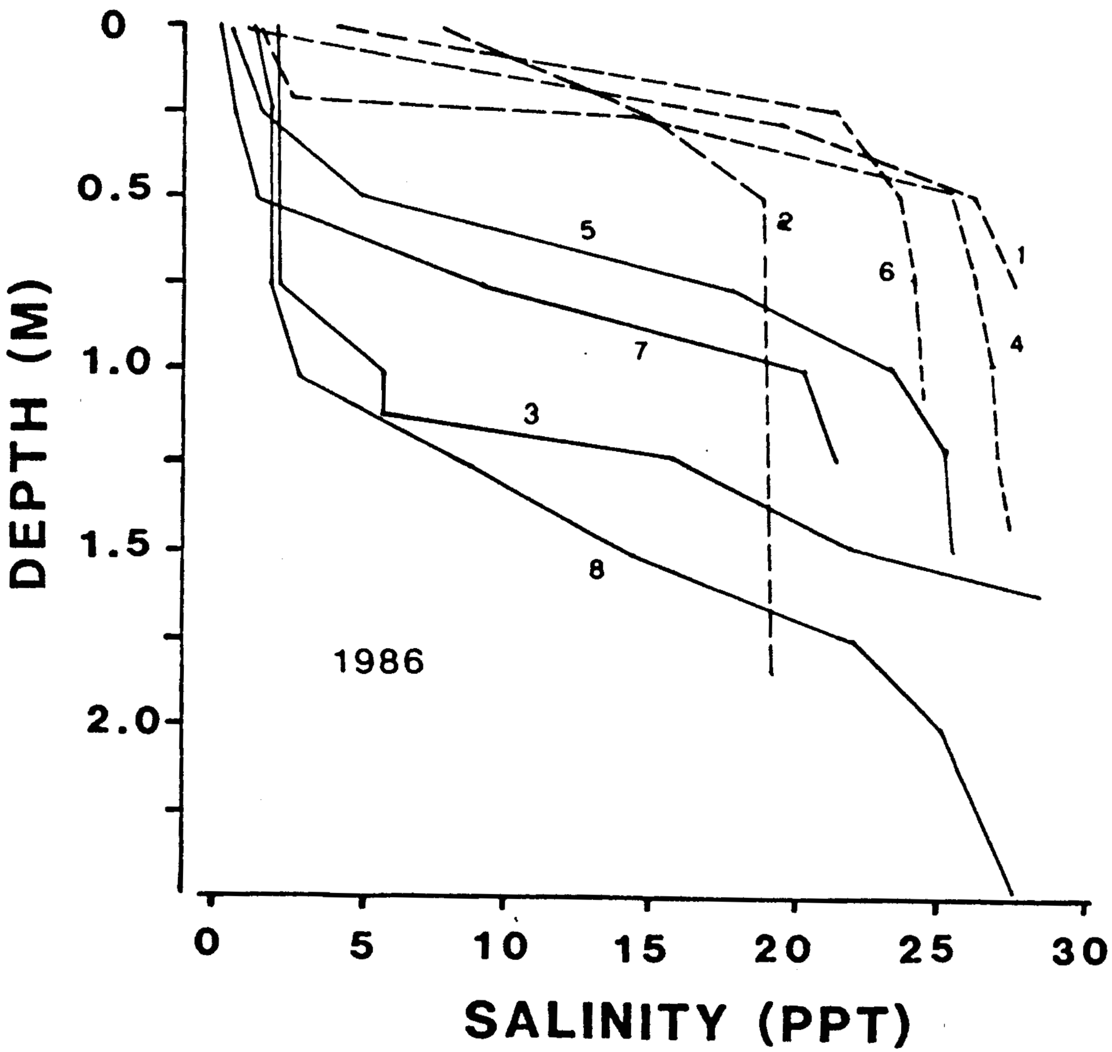

Figure 23. Salinity profiles for San Gregorio Creek lagoon (site 5) for 1986, showing: A) a thick bottom salt water layer when the lagoon was open (dashed lines); and B) thinning of the salt water layer due to freshwater inflow and sandbar seepage after each sandbar closure (solid lines). (Dates: 1 = 19 May; 2 = 23 June; 3 = 8 July; 4 = 16 July; 5 = 24 July; 6 = 24 August; 7 = 24 September; 8 = 19 October)

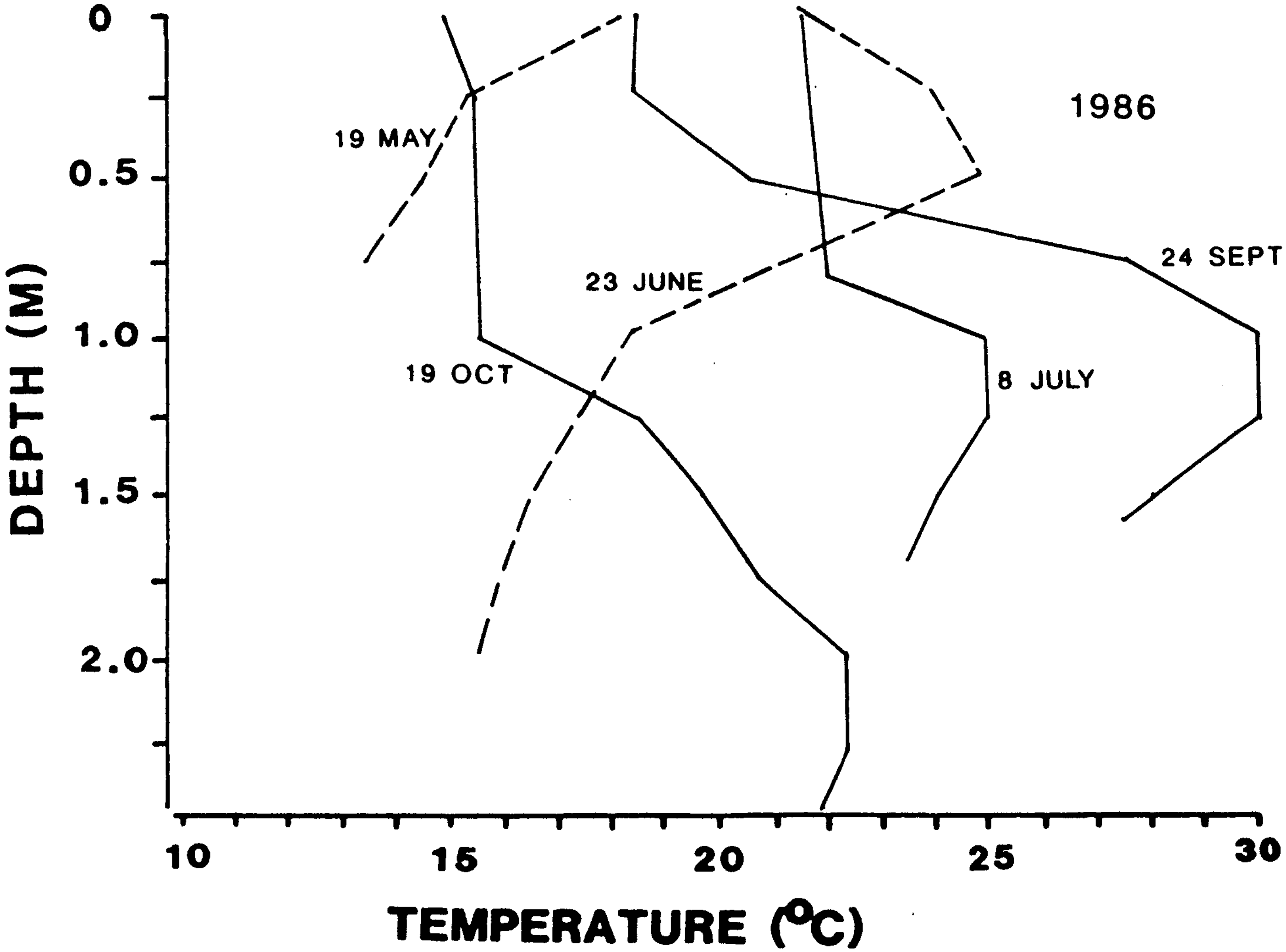

Figure 24. Water temperature profiles for San Gregorio Creek lagoon (site 5) for 1986, showing: A) cooler water within the bottom salt water lens when the lagoon was open to tidal mixing (19 May, 23 June); and B) relatively warmer water within the bottom salt water lens when the lagoon was closed (8 July, 24 September, and 19 October), including extremely high bottom water temperatures on 24 September.

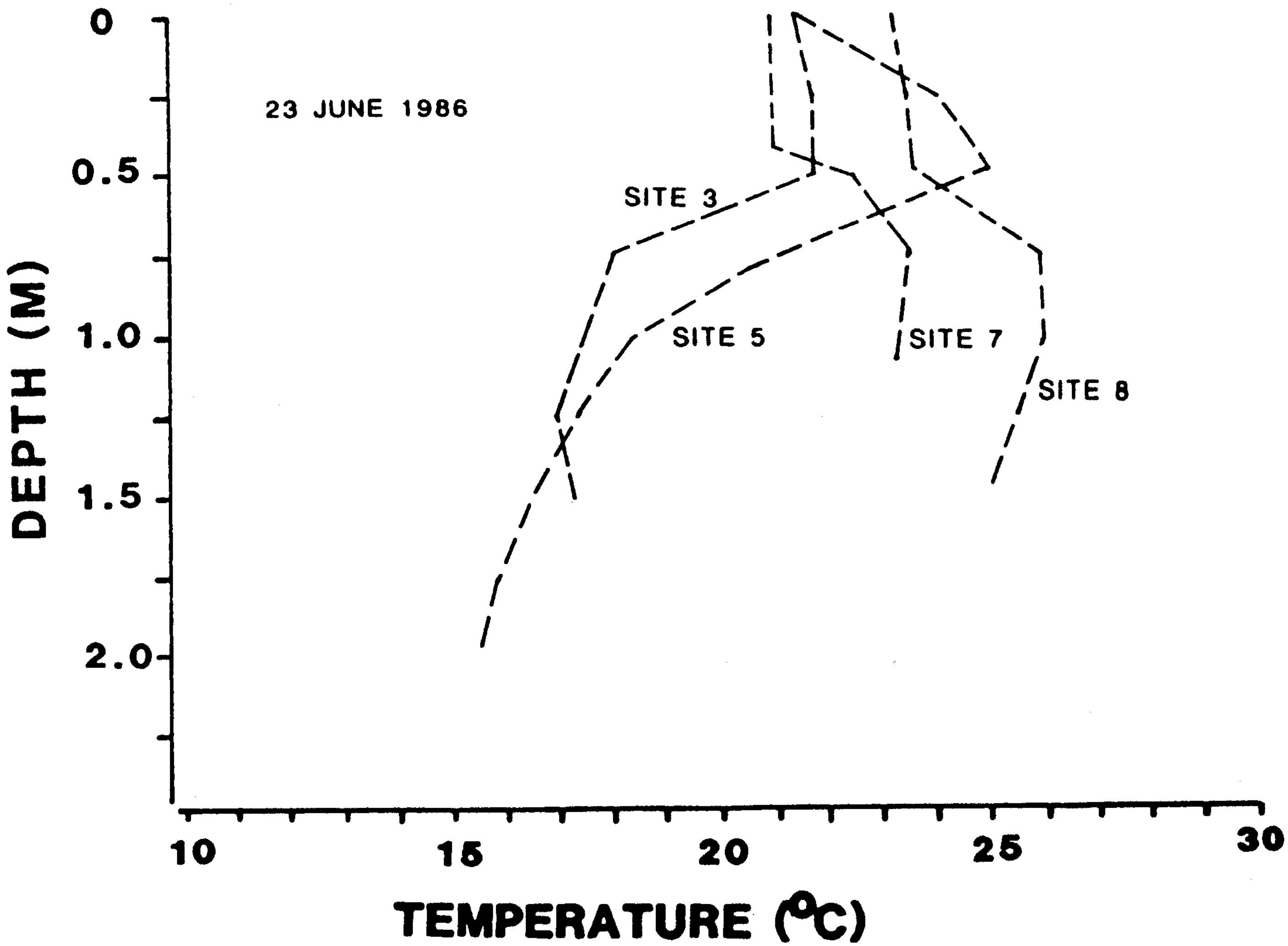

Figure 25. Water temperature profiles for San Gregorio Creek lagoon on 23 June 1986 (when the sandbar was open), showing: A) relatively low water temperatures within the bottom salt water layer at site 3 and 5, which were close to the mouth and subject to tidal inflow and cooling; and B) relatively high water temperatures within the bottom salt water layer at sites 7 and 8, which were further upstream and not subject to tidal mixing and cooling.

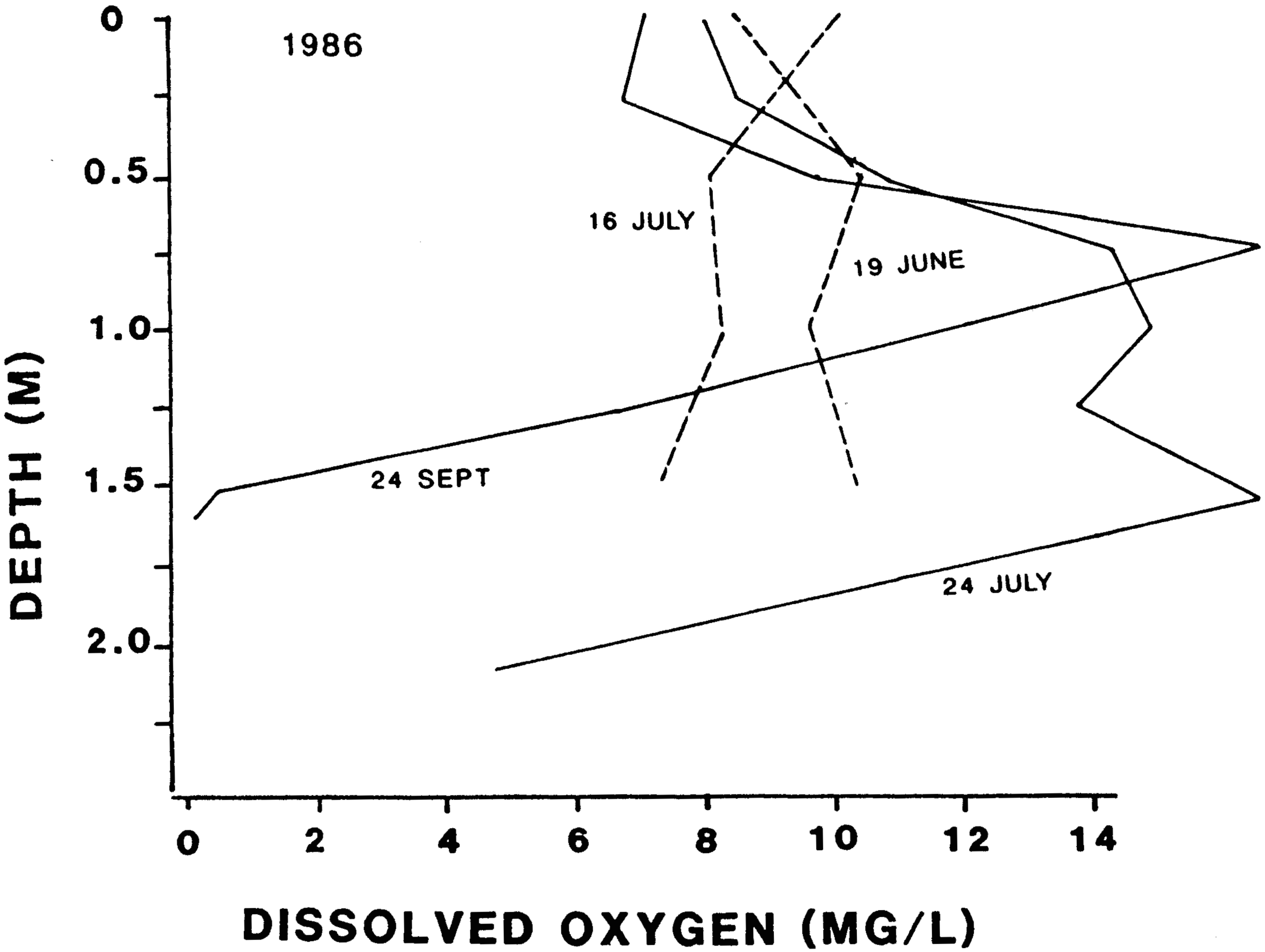

Figure 26. Dissolved oxygen profiles for San Gregorio Creek lagoon (site 5) for 1986, showing: A) unstratified dissolved oxygen conditions on 19 June and 16 July, when the sandbar was open to tidal mixing; and B) stratified dissolved oxygen conditions, with supersaturated oxygen at the top of the salt water lens and very low bottom dissolved oxygen, on 24 July and 24 September, when the sandbar was closed.

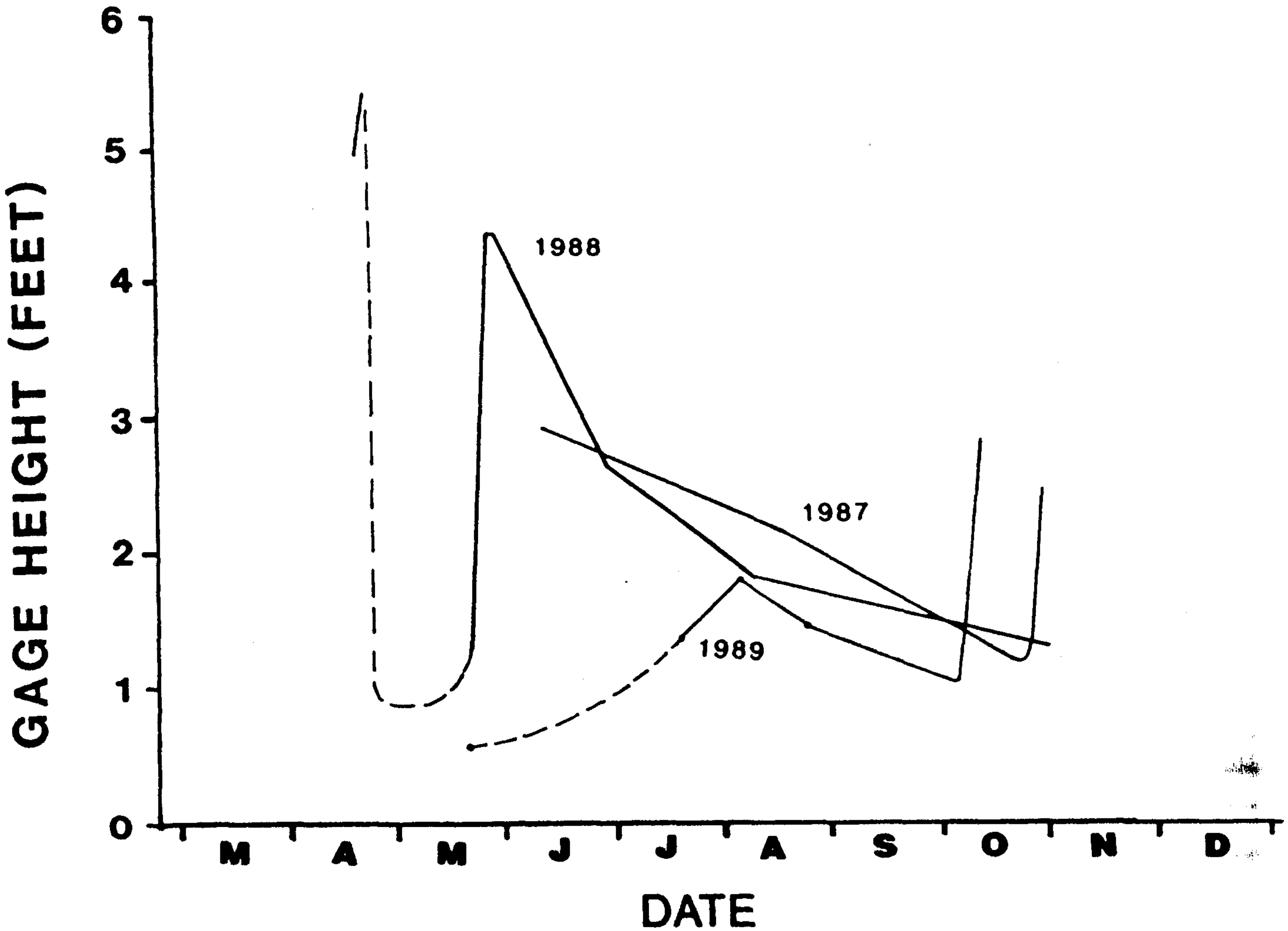

Figure 27. Water levels for San Gregorio Creek lagoon for 1987, 1988, and 1989, showing: A) progressive decline in summer water level in 1987, due to very low streamflow, evaporation, and sandbar seepage, with rise in late October, due to rain; B) early sandbar formation in 1988, late April breach due to rain, bar reformation in May, and progressive decline in summer, due to very low streamflows, evaporation, and sandbar seepage; and C) early July sandbar formation in 1989, with declining water levels until October increase in streamflow.

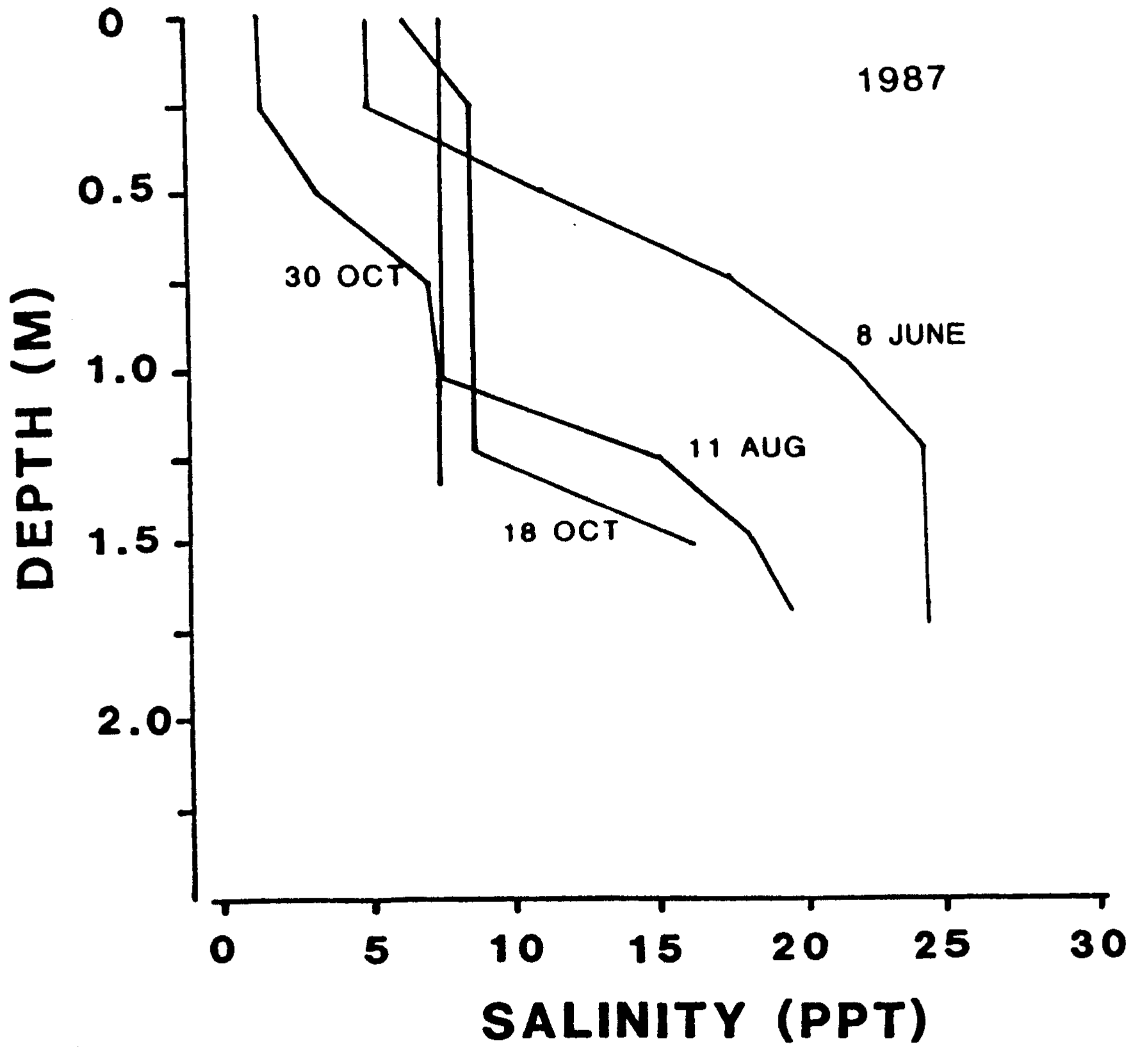

Figure 28. Salinity profiles for San Gregorio Creek lagoon (site 5) for 1987, showing: A) thinning of the salt water lens from 8 June to 11 August, due to freshwater inflow and sandbar seepage; B) little change in mean water column salinity between 11 August and 18 October, due to lack of freshwater inflows; and C) reduction in lagoon salinity between 18 October and 30 October, due to freshwater inflows from late October rains.

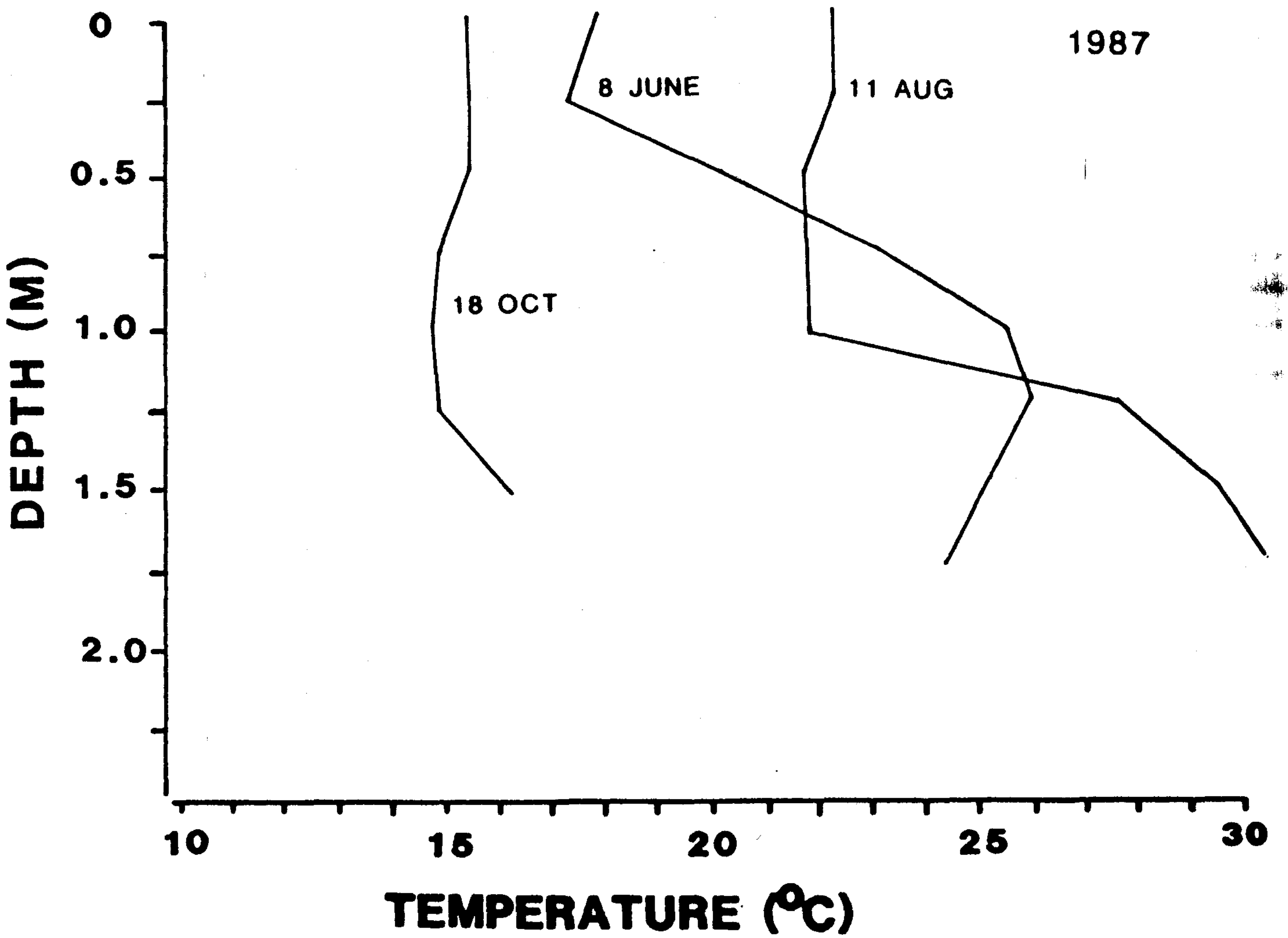

Figure 29. Water temperature profiles for San Gregorio Creek lagoon (site 5) for 1987, showing: A) temperature stratification with water temperatures within the bottom salt water lens on 8 June and 11 August; and B) only slight temperature stratification on 18 October, when salinity stratification was less pronounced.

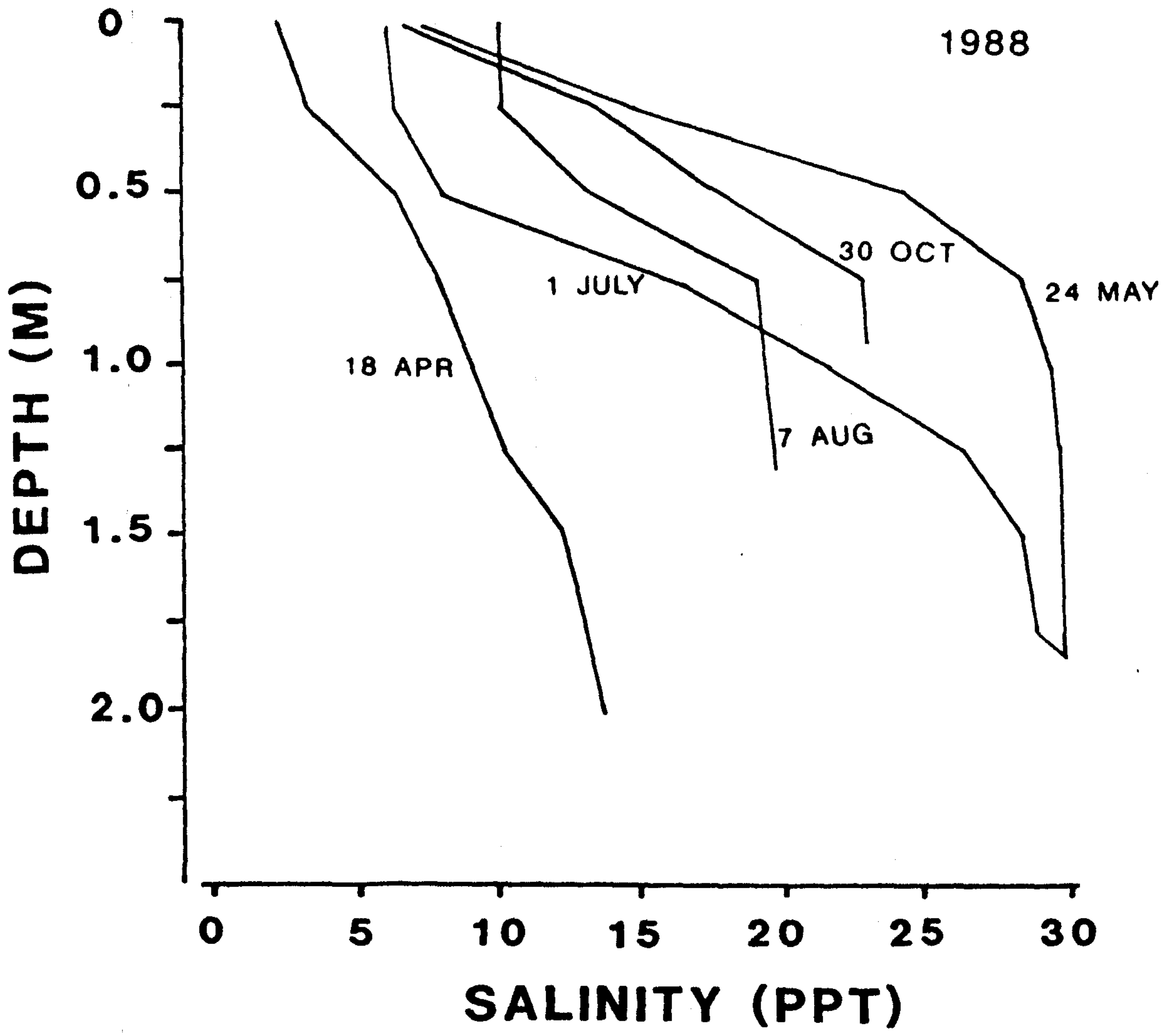

Figure 30. Salinity profiles for San Gregorio Creek lagoon (site 5) for 1988, showing: A) substantial freshwater conversion behind early sandbar on 18 April; B) much saltier conditions on 24 May, after late April sandbar breach and mid May sandbar formation; C) thinning of the salt water lens between 24 May and 1 July due to freshwater inflow and sandbar seepage; D) no change in mean water column salinity between 1 July and 7 August, due to lack of freshwater inflows; and E) increase in bottom salinity between 7 August and 30 October, possibly due to seepage of ocean water through the sandbar into the shallow lagoon.

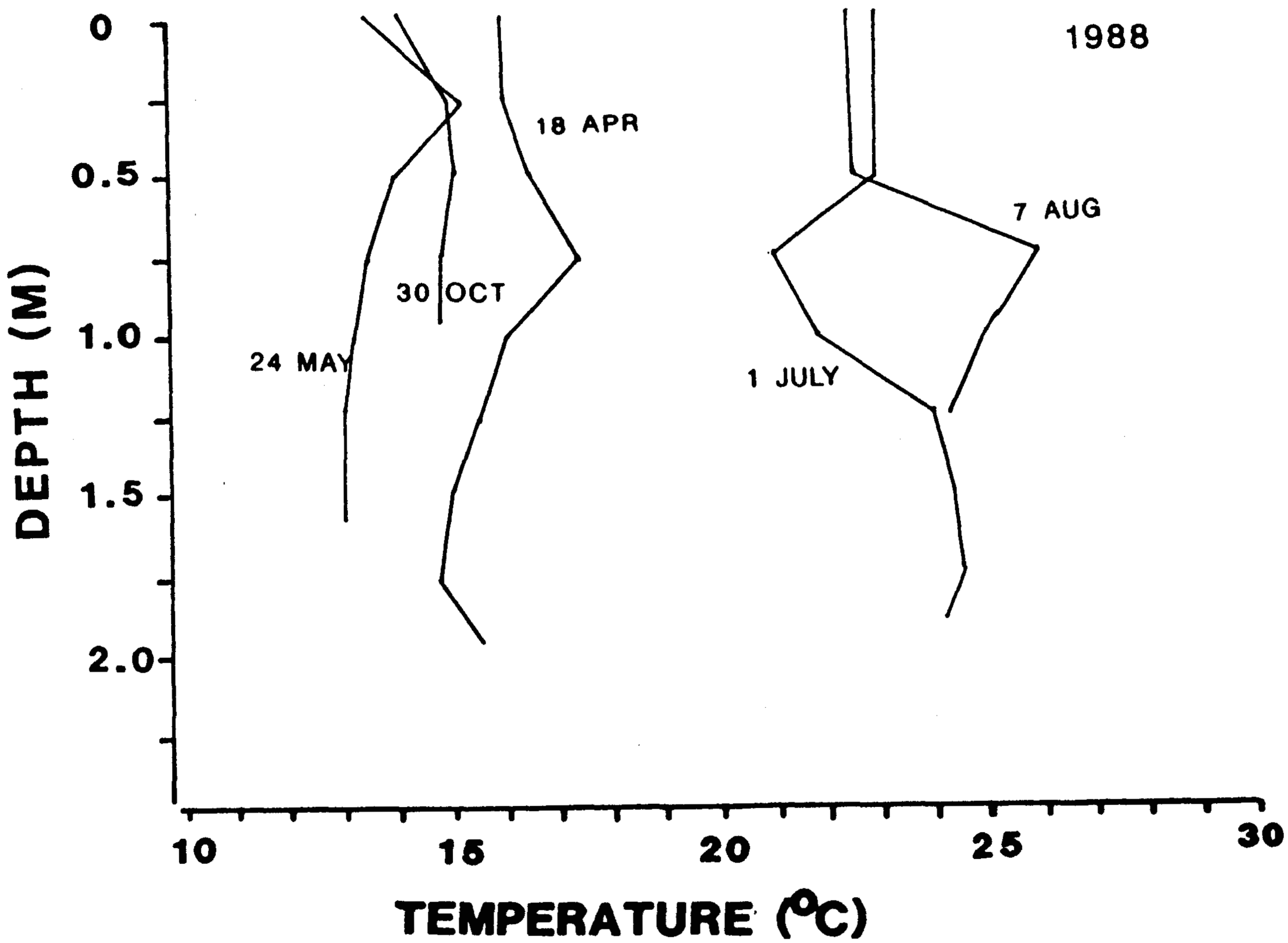

Figure 31. Water temperature profiles for San Gregorio Creek lagoon (site 5) for 1988, showing: A) lower water temperatures within the bottom salt water layer immediately after sandbar formation on 18 April and 24 May; B) higher water temperatures within the bottom salt water lens on 1 July and 7 August; and C) lack of temperature stratification in the very shallow lagoon on 30 October.

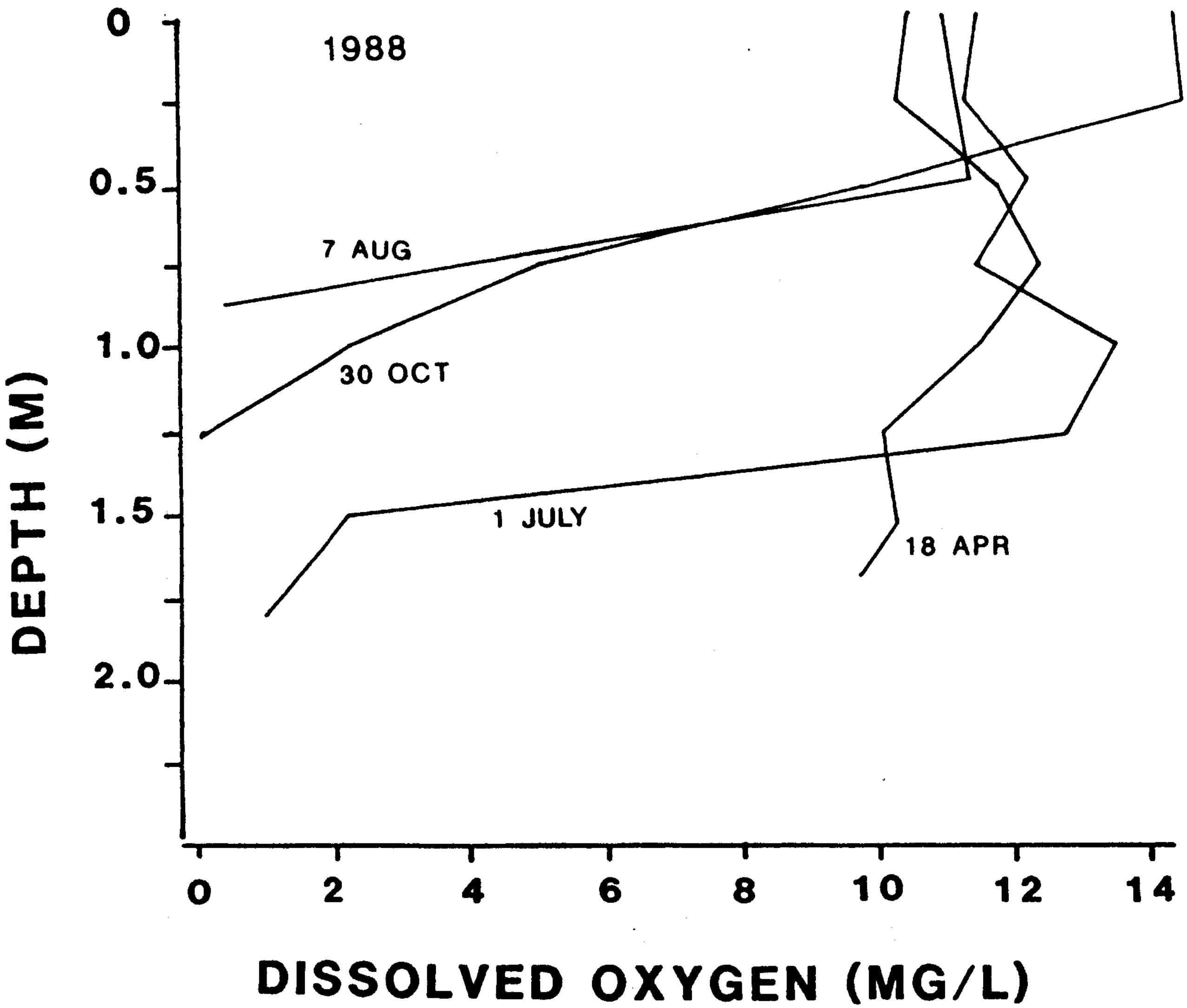

Figure 32. Dissolved oxygen profiles for San Gregorio Creek lagoon (site 5) for 1988, showing: A) good dissolved oxygen levels throughout water column after early sandbar formation on 18 April; B) very low dissolved oxygen at the bottom of the salt water lens on 1 July, 7 August, and 30 October.

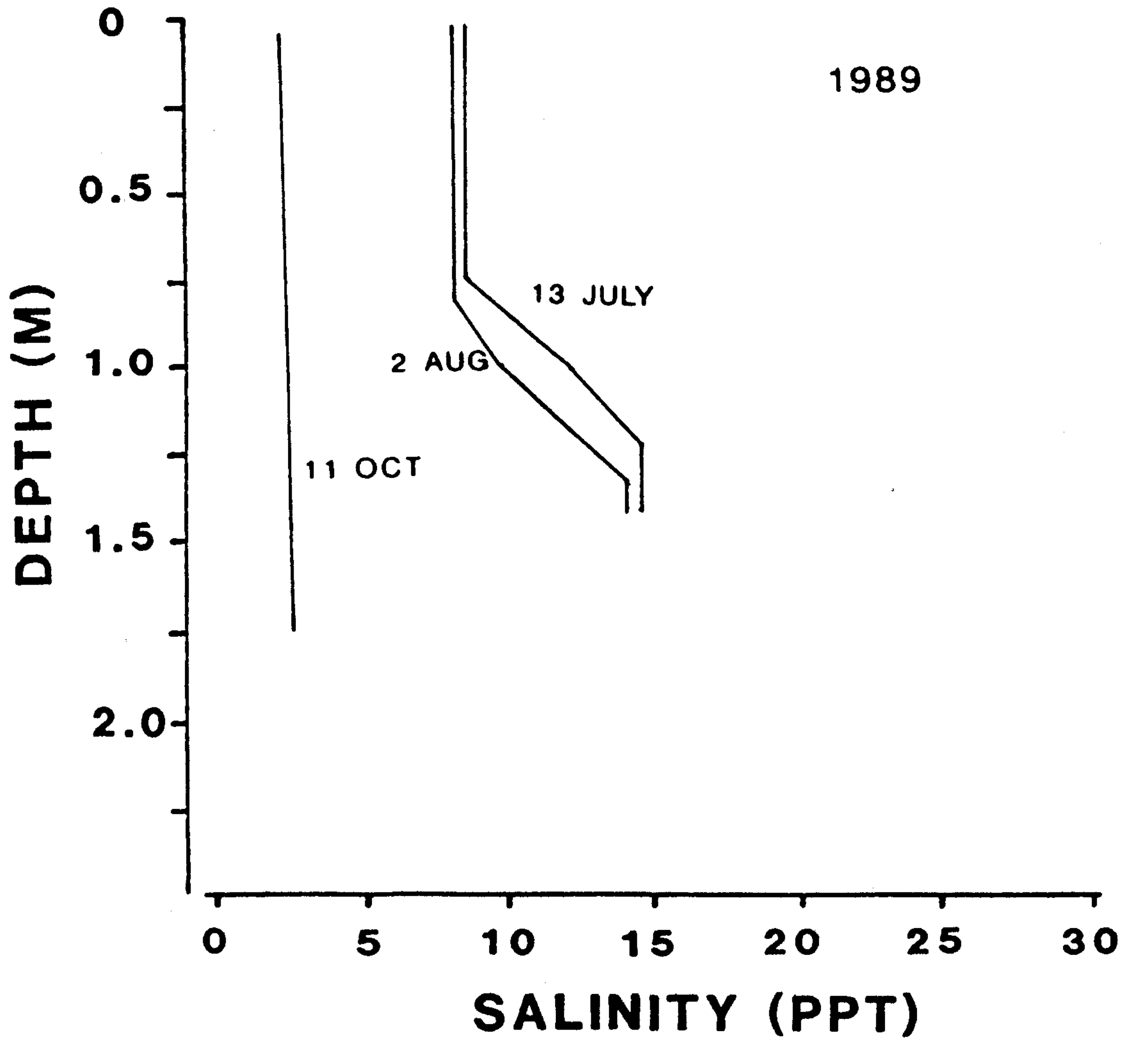

Figure 33. Salinity profiles for San Gregorio Creek lagoon (site 5) for 1989, showing: A) stratification in the brackish lagoon on 13 July and 2 August; and B) lack of stratification on 11 October, after streamflows increased due to reduced diversion and mid-September rain.

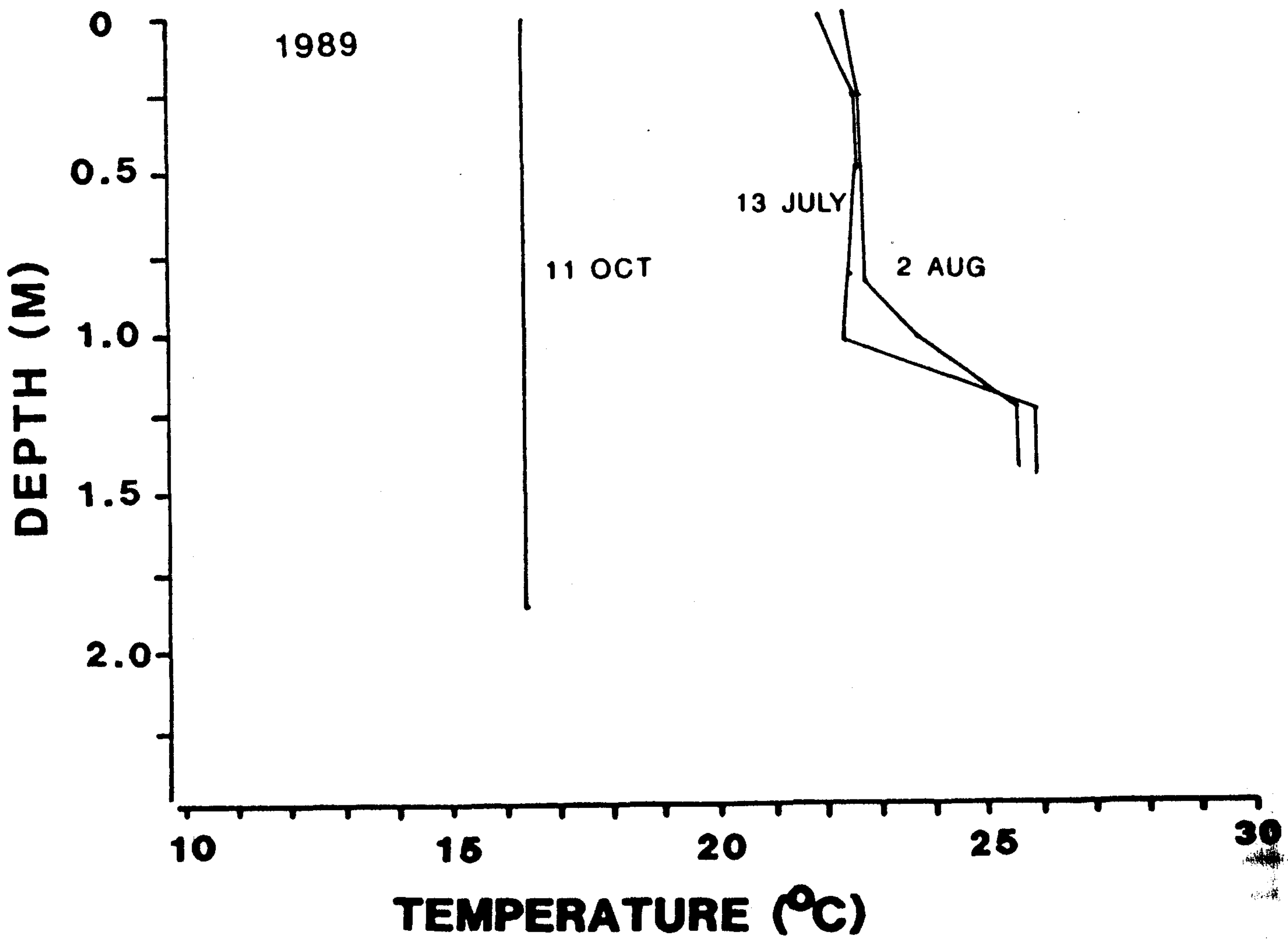

Figure 34. Water temperature profiles for San Gregorio Creek lagoon (site 5) for 1989, showing: A) high water temperatures within the bottom salt water lens on 13 July and 2 August; and B) lack of temperature stratification on 11 October, after salinity stratification had been eliminated by stream inflows.

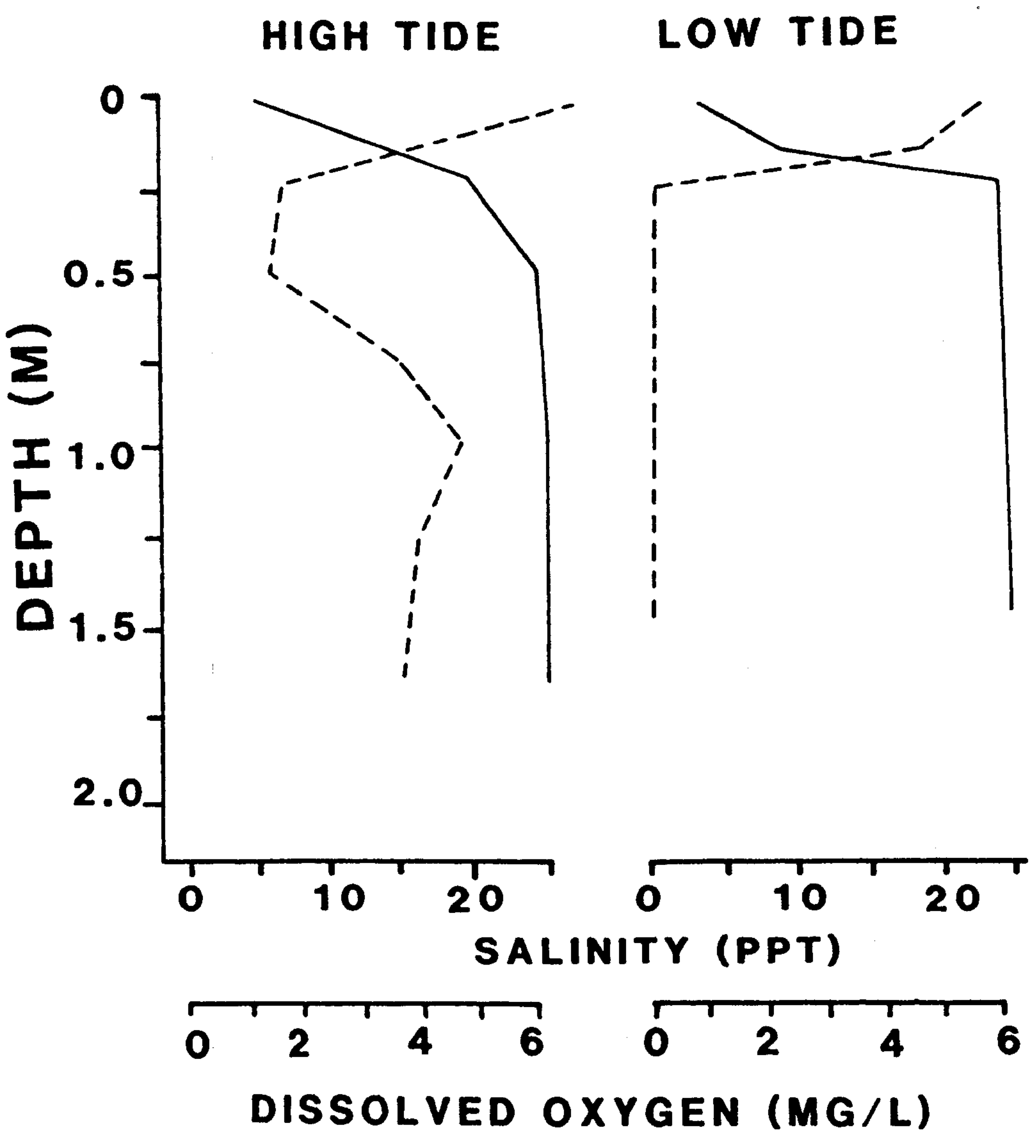

Figure 35. Salinity (solid lines) and dissolved oxygen (dashed lines) profiles for Waddell Creek lagoon (site 3: Highway 1 bridge) for 30, 31 July, following sandbar breaching and tidal kelp deposition, showing: A) moderate dissolved oxygen levels within the salt water wedge during high tide; and B) depletion of dissolved oxygen within the salt water wedge 12 hours later, during low tide.

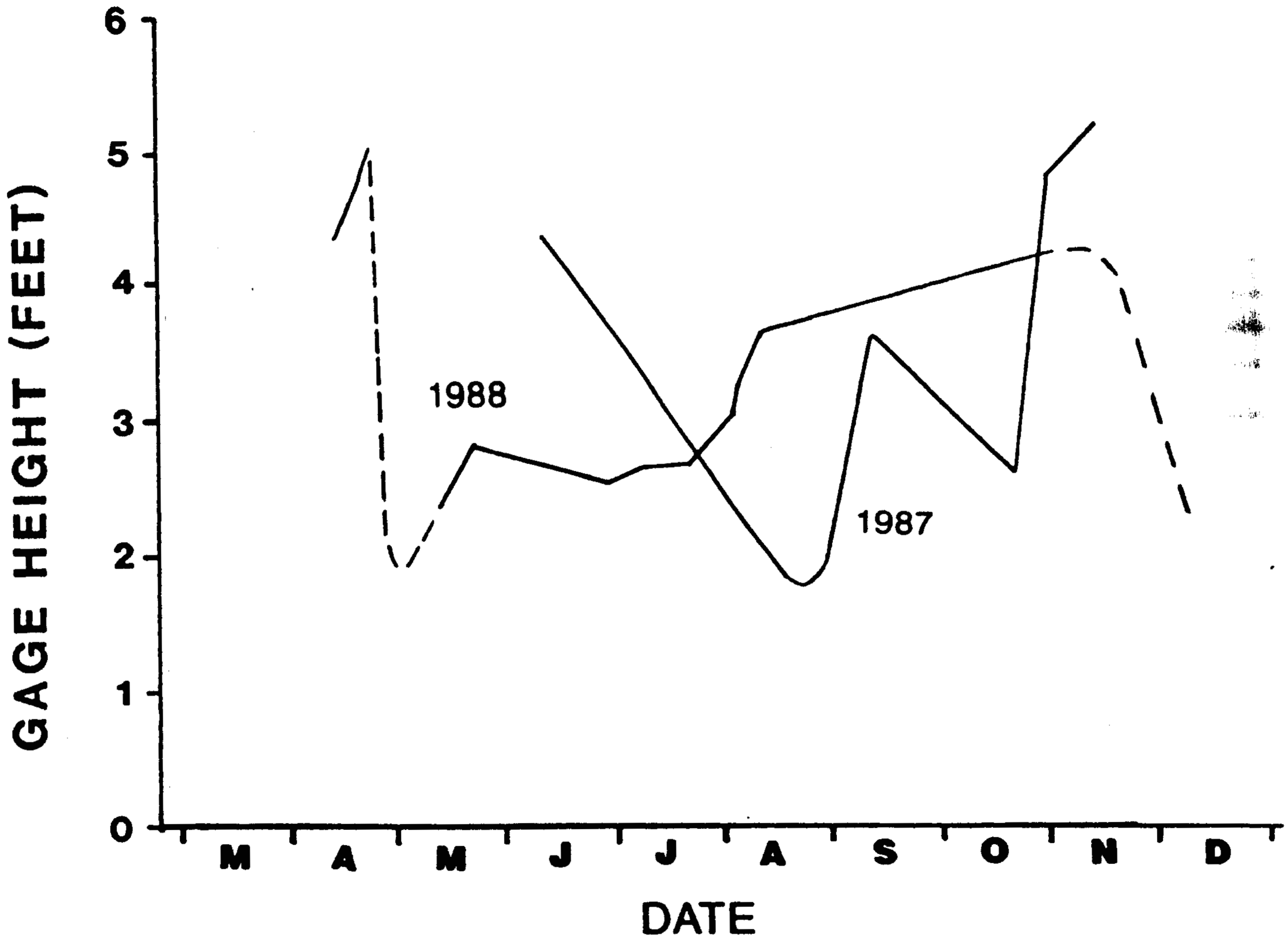

Figure 36. Water levels for Waddell Creek lagoon for 1987 and 1988, showing: A) substantial fluctuation in lagoon level in 1987, due to variation in diversion rate upstream of the lagoon; and B) early sandbar formation and subsequent breaching in 1988 and variable lagoon level after sandbar reformed, due to variation in diversion rate upstream of the lagoon.

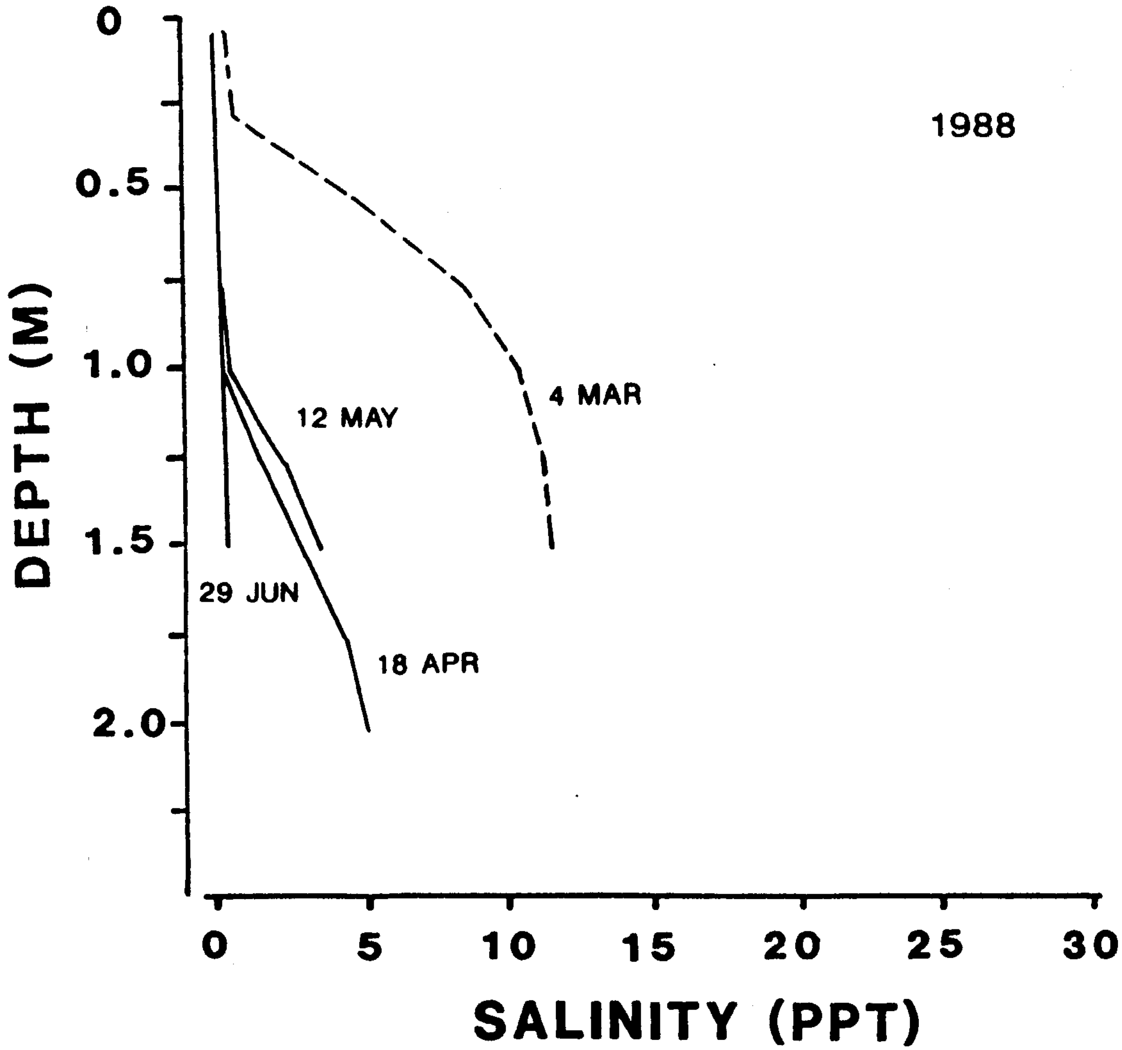

Figure 37. Salinity profiles for Waddell Creek lagoon (site 3) for 1988, showing: A) thinning and dilution of the salt water lens between 4 March and 18 April, due to freshwater inflow and sandbar seepage; B) relatively small salt water lens on 12 May, after late April sandbar breach and reformation; and C) loss of the salt water lens between 12 May and 29 June, due to freshwater inflow and sandbar seepage.

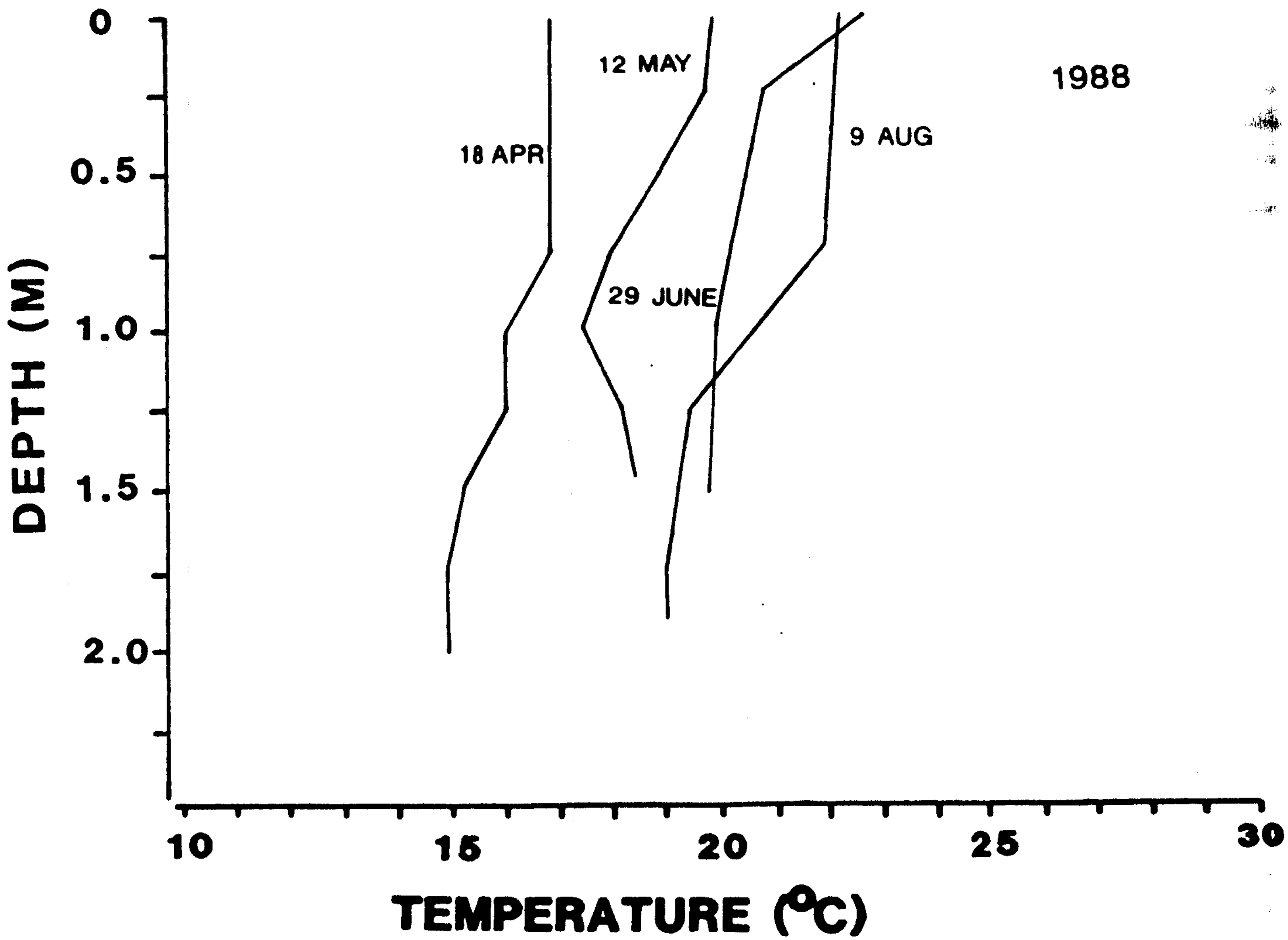

Figure 38. Water temperature profiles for Waddell Creek lagoon (site 3) for 1988, showing relatively low and unstratified temperatures in the freshwater lagoon throughout late spring and summer.

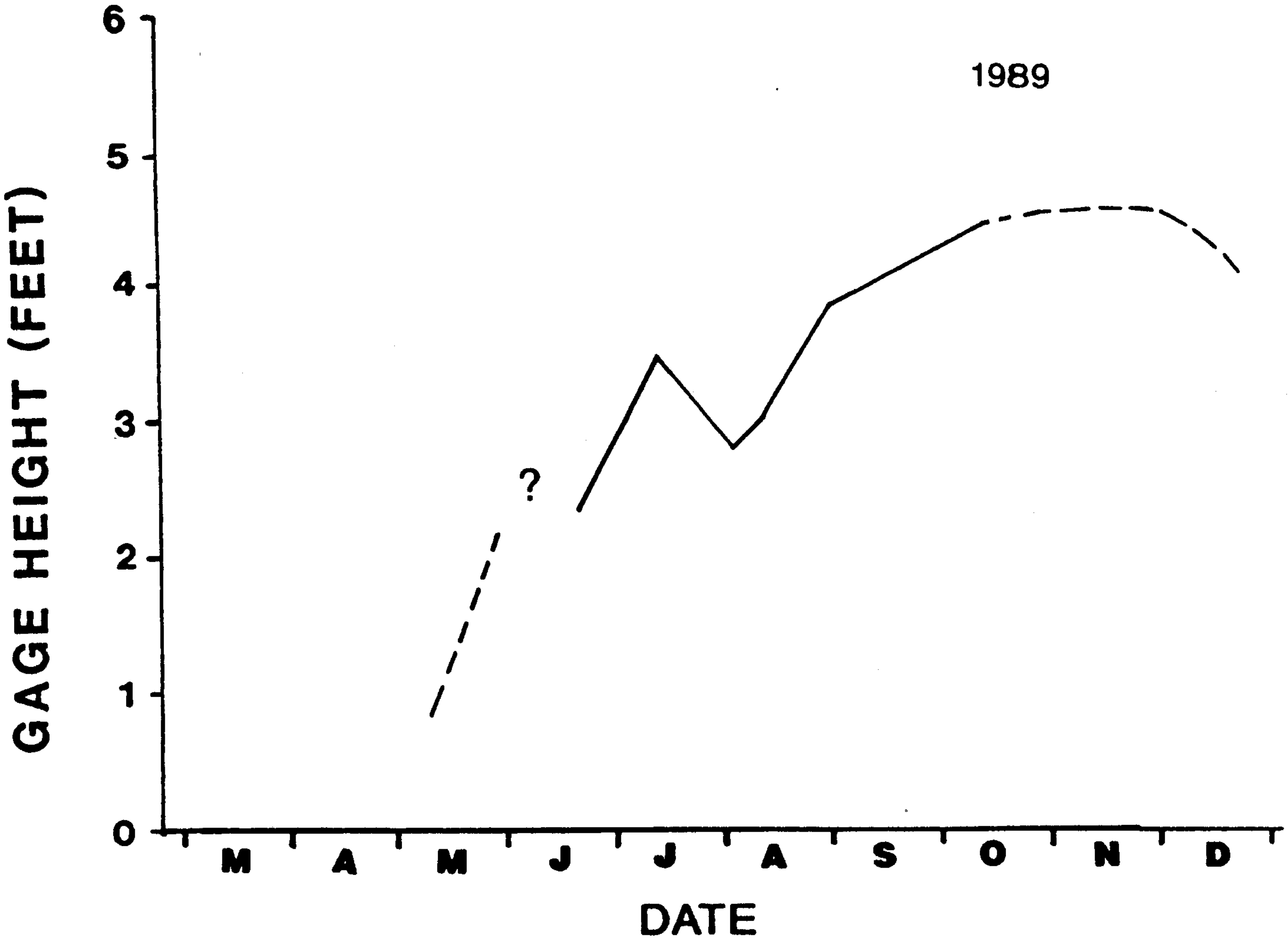

Figure 39. Water levels for Waddell Creek lagoon for 1989, showing: A) possible sandbar formation and breaching in early June (based upon salinity data); B) fluctuation in lagoon water level with variation in diversion rate upstream of lagoon in July and August; and C) maintenance of high lagoon levels in October - November despite partial opening of sandbar, due to increased streamflows after the Loma Prieta earthquake and early rains.

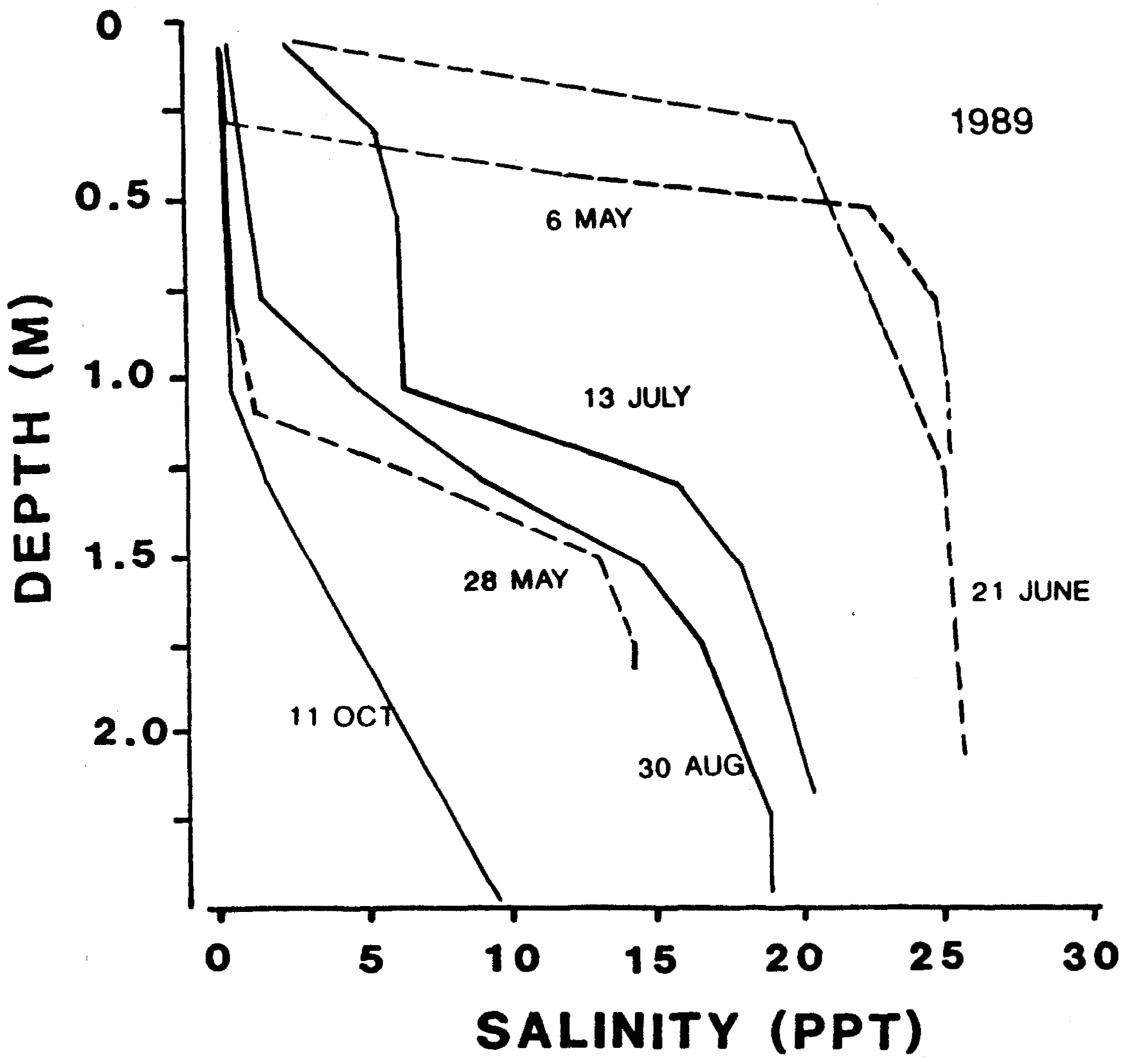

Figure 40. Salinity profiles for Waddell Creek lagoon (site 3) for 1989, showing: A) reduction in thickness of the bottom salt water layer in the partially closed lagoon between 6 May and 24 May, due to freshwater inflow and sandbar seepage; B) increased thickness of the salt water layer between 28 May and 21 June, due to increased outlet size and tidal mixing (possibly sandbar formation and breaching); C) reduction in the thickness of the bottom salt water layer between 21 June and 13 July, due to sandbar formation, freshwater inflow, and sandbar seepage; and D) reduction in lagoon salinity between 30 August and 11 October, due to increased streamflow.

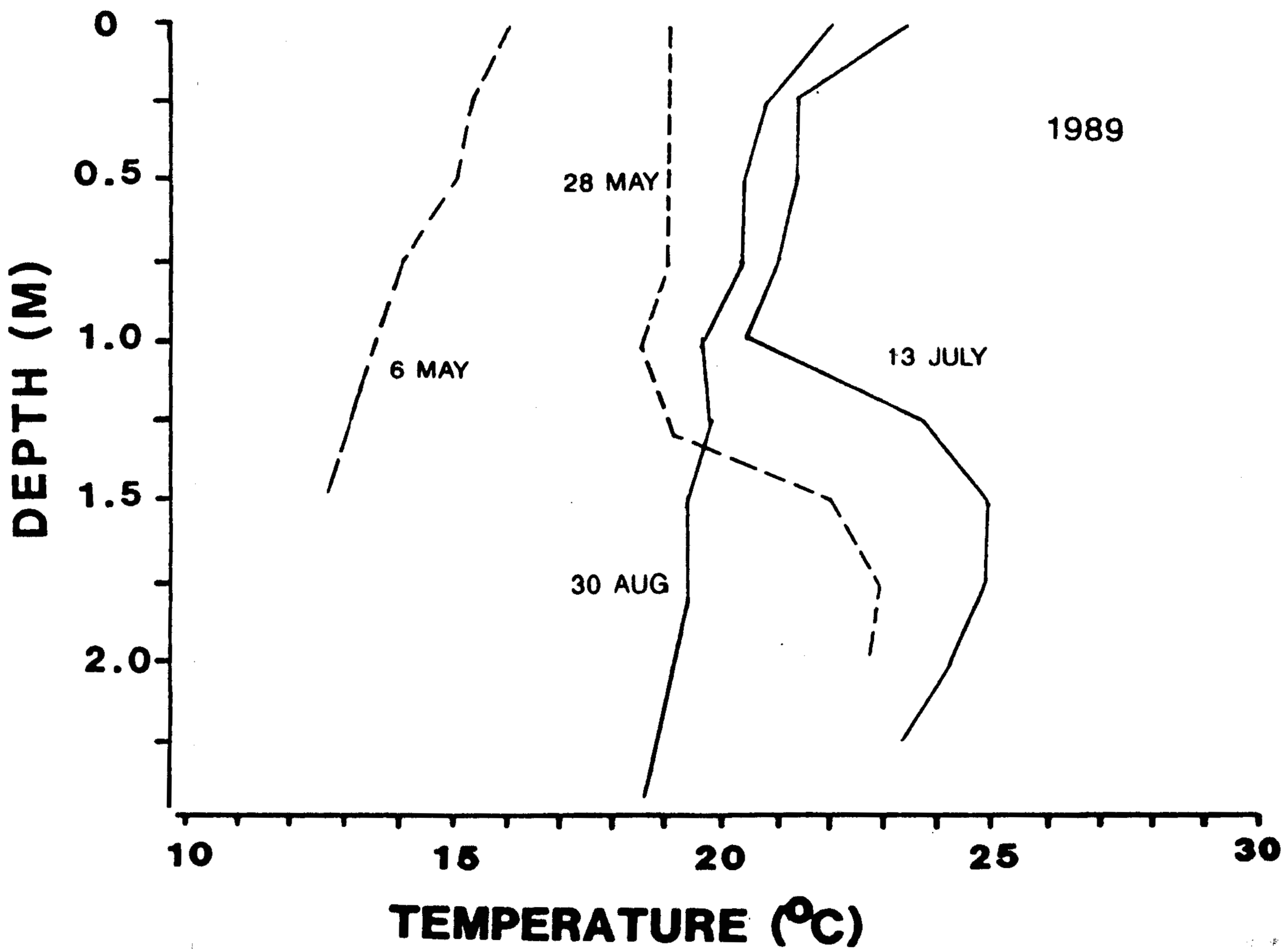

Figure 41. Water temperature profiles for Waddell Creek lagoon (site 3) for 1989, showing: A) cool bottom waters in open, tidally mixed lagoon on 6 May; B) high water temperatures within the bottom salt water layer in the partially closed (28 May) and closed (13 July) lagoon; and C) cool bottom waters on 30 August, despite the salt water layer, due to water column shading by very dense pondweed.

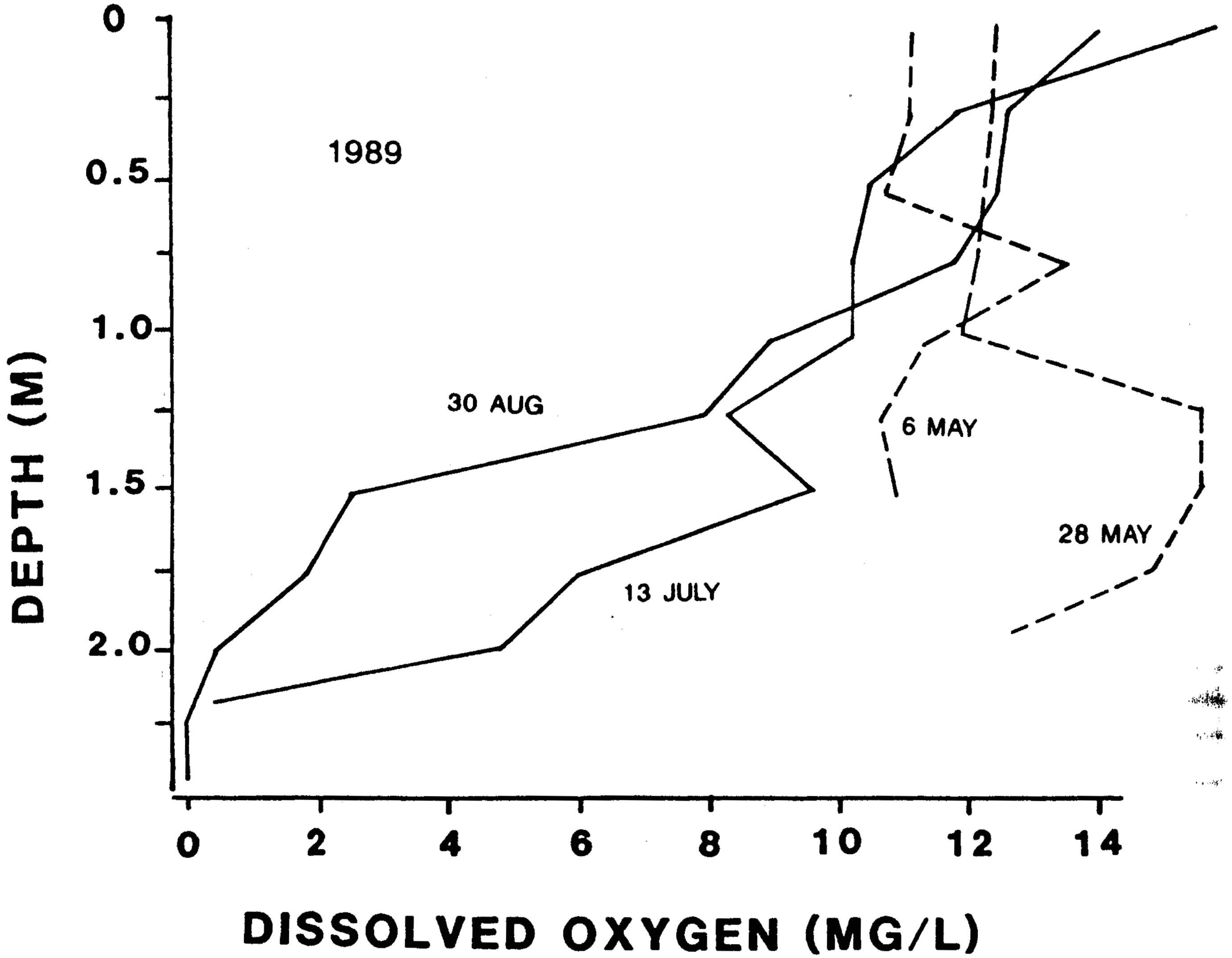

Figure 42. Dissolved oxygen profiles for Waddell Creek lagoon (site 3) for 1989, showing: A) good dissolved oxygen levels in the partailly open and tidally mixed lagoon on 6 May and 28 May; and B) very low dissolved oxygen levels at the bottom of the salt water lens in the closed lagoon on 13 July and 30 August, due to poor mixing and dense pondweed growth.

PESCADERO CREEK STEELHEAD STANDARD LENGTHS (mm)

1985

```
       25,27 MAY               13 AUGUST              2 NOVEMBER
       (n = 108)               (n = 236)              (n = 347)

 40    X
       X
 50    XXXXXXXXXX
       XXXXXXXXXX
 60    XXXXXXXX
       XXXXXXXX
 70    XXXXXXXXXXX             XXXXXXX
       XXXXXXXXXXX             XXXXXXX
 80    XXXXXXXXXXXXXXXXXXXX    XXXXXXXXXXXX
       XXXXXXXXXXXXXXXXXXXX    XXXXXXXXXXXX
 90    XXXXXXXXXXXXXXXXXXX     XXXXXXXXXXXXXX         X
       XXXXXXXXXXXXXXXXXXX     XXXXXXXXXXXXXX         X
100    XXXXX                   XXXXXXXXXXXXX          XXX
       XXXXX                   XXXXXXXXXXXXX          XXX
110    XXXXX                   XXXXXXXXXXXXXXXXXX     XXXXXX
       XXXXX                   XXXXXXXXXXXXXXXXXX     XXXXXX
120    XXX                     XXXXXXXXXXXXXXX        XXXXXXXX
       XXX                     XXXXXXXXXXXXXXX        XXXXXXXX
130    XXXX                    XXXXXXXXXXXX           XXXXXXXX
       XXXX                    XXXXXXXXXXXX           XXXXXXXX
140    XXX                     XXXXXXXX               XXXXXXXX
       XXX                     XXXXXXXX               XXXXXXXX
150    XX                      XXXX                   XXXXXXXXXX
       XX                      XXXX                   XXXXXXXXXX
160    X                       X                      XXXXXXXXXXXXXXXXXXXXX
       X                       X                      XXXXXXXXXXXXXXXXXXXXX
170                                                   XXXXXXXXXXXXX
                                                      XXXXXXXXXXXXX
180                                                   XXXXXXXXXXXXX
                                                      XXXXXXXXXXXXX
190                                                   XXXXXXX
                                                      XXXXXXX
200                                                   XX
                                                      XX
210                                                   X
                                                      X
220                                                   X
                                                      X
230

240                                                   X
                                                      X
```

Figure 43. Standard lengths of steelhead from Pescadero Creek Lagoon in 1985, showing rapid growth from May to November in the unstratified, freshwater lagoon.

PESCADERO CREEK STEELHEAD STANDARD LENGTHS (mm)

```
      LAGOON                    STREAM
      1985                      1987-89
      2 NOVEMBER                OCTOBER/NOVEMBER
      (n=347)                   (n = 300)

 40                             XX
                                XX
 50                             XXXXXXXXXXXXXXX
                                XXXXXXXXXXXXXXX
 60                             XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                                XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 70                             XXXXXXXXXXXXXXXXXXX
                                XXXXXXXXXXXXXXXXXXX
 80                             XXXXXX
                                XXXXXX
 90      X                      XXXXXXXXX
         X                      XXXXXXXXX
100      XXX                    XXXXXX
         XXX                    XXXXXX
110      XXXXXX                 XX
         XXXXXX                 XX
120      XXXXXXXX               XX
         XXXXXXXX               XX
130      XXXXXXXX               X
         XXXXXXXX               X
140      XXXXXXXX
         XXXXXXXX
150      XXXXXXXXXX             *
         XXXXXXXXXX             *
160      XXXXXXXXXXXXXXXXXXXXX  *
         XXXXXXXXXXXXXXXXXXXXX  *
170      XXXXXXXXXXXXX
         XXXXXXXXXXXXX
180      XXXXXXXXXXXXX
         XXXXXXXXXXXXX
190      XXXXXXX
         XXXXXXX
200      XX
         XX
210      X
         X
220      X
         X
230

240      X
         X
```

Figure 44. Standard lengths of steelhead from Pescadero Creek lagoon in November, 1985 and from Pescadero Creek in October-November of 1987-1989, showing the much larger sizes acheived by fish reared in the lagoon. Also note the bimodal sizes of stream-reared fish.

PESCADERO CREEK LAGOON STEELHEAD STANDARD LENGTHS (mm)

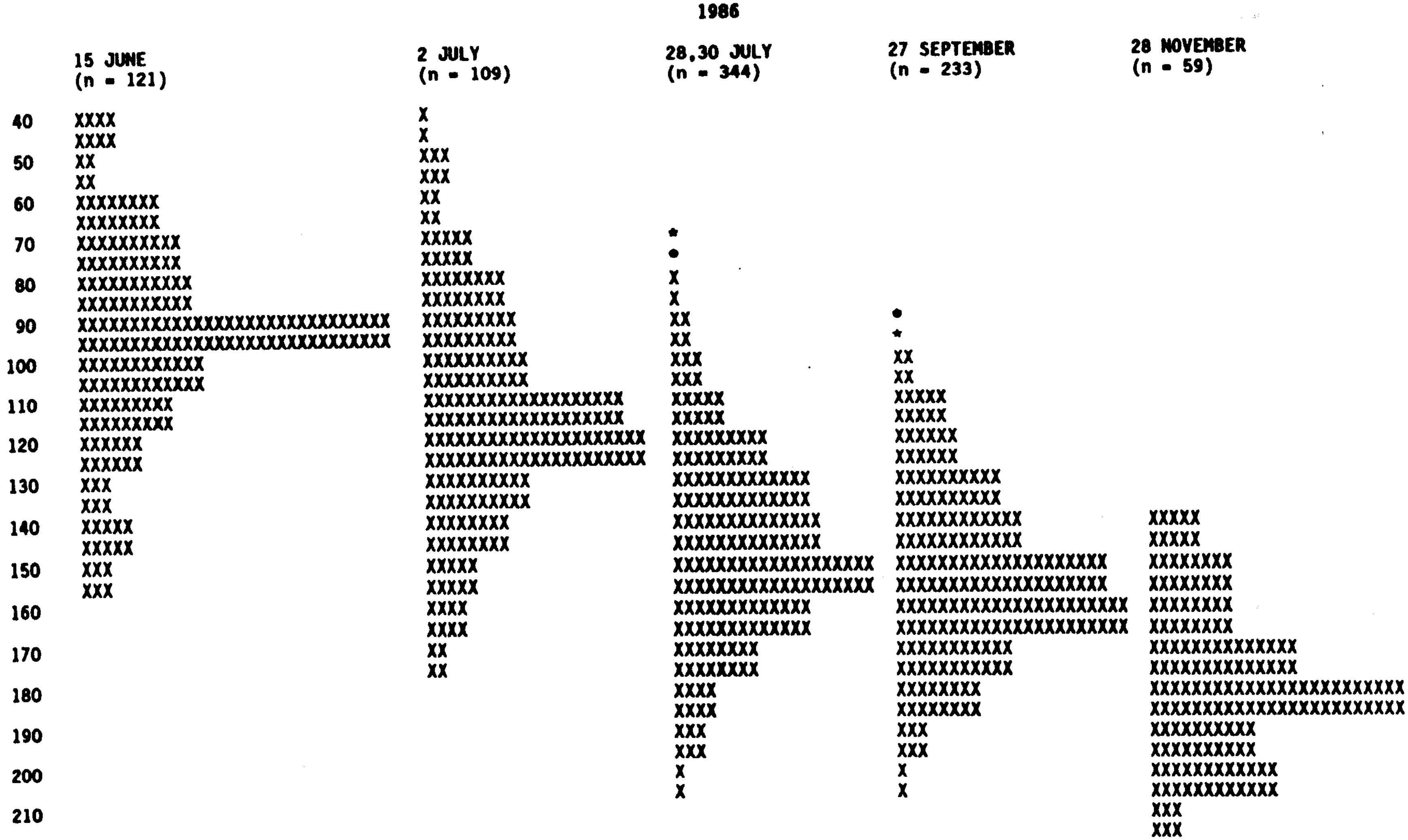

Figure 45. Standard lengths of steelhead from Pescadero Creek Lagoon in 1986 showing: (a) fast growth through June and July, when the lagoon was open to strong tidal mixing; (b) little growth during August and September, when the lagoon was stratified and subject to temperature and dissolved oxygen problems; and (c) fast growth in October and November, when the lagoon was no longer stratified.

PESCADERO CREEK LAGOON STEELHEAD STANDARD LENGTHS (mm)

```
        1988                       1989
        7 AUGUST                   30 SEPTEMBER
        (n = 37)                   (n = 25)

 60     XXXXX
        XXXXX
 70     XXXXXXXXXXXXXXXXXXX
        XXXXXXXXXXXXXXXXXXX
 80     XXXXXXXXXXXXXXXXXXXXXX
        XXXXXXXXXXXXXXXXXXXXXX
 90     XXXXXX
        XXXXXX
100     XX
        XX
110     XXXXXXXXXXX
        XXXXXXXXXXX
120     XXX
        XXX
130     XXXXXXXX
        XXXXXXXX
140

150     XXXXXXXXXXXXXX
        XXXXXXXXXXXXXX
160     XXXXXXXX                   XXXXXXXXXXXX
        XXXXXXXX                   XXXXXXXXXXXX
170                                XXXXXXXXXXXXXXXXXXXX
                                   XXXXXXXXXXXXXXXXXXXX
180                                XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                                   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
190                                XXXXXXXXXXXXXXXXXXX
                                   XXXXXXXXXXXXXXXXXXX
200                                XXXXXXXX
                                   XXXXXXXX
```

Figure 46. Standard lengths of steelhead from Pescadero Creek Lagoon in 1988 and 1989, showing relatively small fish and bimodal size distribution from the stratified, brackish lagoon of 1988 and uniformly large fish from the tidally mixed lagoon of 1989.

SAN GREGORIO CREEK LAGOON STEELHEAD STANDARD LENGTHS (mm)

```
                      1985

       11 JUNE                    10 NOVEMBER
       (n = 59)                   (n = 59)

 50    XXXXX
       XXXXX
 60    XXXXXXXXXXXX
       XXXXXXXXXXXX
 70    XXXXXXXXXXXXXX
       XXXXXXXXXXXXXX
 80    XXXXX
       XXXXX
 90    XXXXXXX
       XXXXXXX
100    XXXXXXXXXXXXXXXXXXXX        XXX
       XXXXXXXXXXXXXXXXXXXX        XXX
110    XXXXXXXXXXXXXXXXXXXXXX      XX
       XXXXXXXXXXXXXXXXXXXXXX      XX
120    XXXXXXXXXX                  XXXXXXX
       XXXXXXXXXX                  XXXXXXX
130    XX                          XXXXXXXXXXXX
       XX                          XXXXXXXXXXXX
140    X                           XXXXXXXXXXXXXXXXX
       X                           XXXXXXXXXXXXXXXXX
150                                XXXXXXXXXXXXXXXXX
                                   XXXXXXXXXXXXXXXXX
160                                XXXXXXXXXXXXXXXXX
                                   XXXXXXXXXXXXXXXXX
170                                XXXXXXXXXX
                                   XXXXXXXXXX
180                                XXXXXXXXX
                                   XXXXXXXXX
190                                XXX
                                   XXX
200

210

220                                XXX
                                   XXX
```

Figure 47. Standard lengths of steelhead from San Gregorio Creek Lagoon in 1985, showing fast summer growth and conversion of bimodal size distribution present in June to unimodal size distribution by November.

SAN GREGORIO CREEK LAGOON STEELHEAD STANDARD LENGTHS (mm)

1986

	23 JUNE (n = 482)	16 JULY (n = 318)	19 OCTOBER (n = 246)
40	XXX		
	XXX		
50	XXXXXXXXX	XXXXX	XX
	XXXXXXXXX	XXXXX	XX
60	XXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXX	XXXXXXXXX
	XXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXX	XXXXXXXXX
70	XXXXXXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXXXX
	XXXXXXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXXXX
80	XXXXXX	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXX
	XXXXXX	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXX
90	XXX	XXXXXXXXXXX	XXXXXXXXXXXX
	XXX	XXXXXXXXXXX	XXXXXXXXXXXX
100	XXXXXX	XXX	XXXXXXXX
	XXXXXX	XXX	XXXXXXXX
110	XXXXXXXXXXX	XXXXXX	XXXXXXXXXXXXX
	XXXXXXXXXXX	XXXXXX	XXXXXXXXXXXXX
120	XXXXXXXXXXXXXX	XXXXX	XXXXXXXX
	XXXXXXXXXXXXXX	XXXXX	XXXXXXXX
130	XXXXXXXXX	XXXXXX	XXXXXXXXXXX
	XXXXXXXXX	XXXXXX	XXXXXXXXXXX
140	XXXX	XX	XXXXXXXXXXX
	XXXX	XX	XXXXXXXXXXX
150			XXX
			XXX
160			XX
			XX
170			X
			X
180			●
			*

Figure 48. Standard lengths of steelhead from San Gregorio Creek Lagoon in 1986, showing relatively little summer growth, due to summer sandbar breaching and lagoon stratification.

SAN GREGORIO CREEK LAGOON STEELHEAD STANDARD LENGTHS (mm)

```
       1985                   1986                   1988
       10 NOV                 19 OCT                 4 DEC
       (n = 59)               (n = 246)              (n = 12)

 50                           XX
                              XX
 60                           XXXXXXXXX
                              XXXXXXXXX
 70                           XXXXXXXXXXX
                              XXXXXXXXXXX
 80                           XXXXXXXXXX
                              XXXXXXXXXX
 90                           XXXXXXXXXXXX
                              XXXXXXXXXXXX
100    XXX                    XXXXXXXX
       XXX                    XXXXXXXX
110    XX                     XXXXXXXXXXXXX      XXXXXXXX
       XX                     XXXXXXXXXXXXX      XXXXXXXX
120    XXXXXXX                XXXXXXXX           XXXXXXXX
       XXXXXXX                XXXXXXXX           XXXXXXXX
130    XXXXXXXXXXXX           XXXXXXXXXXX        XXXXXXXX
       XXXXXXXXXXXX           XXXXXXXXXXX        XXXXXXXX
140    XXXXXXXXXXXXXXXXX      XXXXXXXXXXX        XXXXXXXXXXXXXXXXXXXXXXXXX
       XXXXXXXXXXXXXXXXX      XXXXXXXXXXX        XXXXXXXXXXXXXXXXXXXXXXXXX
150    XXXXXXXXXXXXXXXXX      XXX                XXXXXXXXXXXXXXXXX
       XXXXXXXXXXXXXXXXX      XXX                XXXXXXXXXXXXXXXXX
160    XXXXXXXXXXXXXXXXX      XX                 XXXXXXXXXXXXXXXXXXXXXXXXX
       XXXXXXXXXXXXXXXXX      XX                 XXXXXXXXXXXXXXXXXXXXXXXXX
170    XXXXXXXXXX             X                  XXXXXXXX
       XXXXXXXXXX             X                  XXXXXXXX
180    XXXXXXXXX              •
       XXXXXXXXX              *
190    XXX
       XXX
200

210

220    XXX
       XXX
```

Figure 49. Standard lengths of steelhead from San Gregorio Creek Lagoon in October - December of 1985, 1986 and 1988, showing unimodal large sizes in 1985, when the lagoon converted to unstratified, low salinity conditions, and smaller mean size and bimodal size frequency in 1986, when periodic summer breaching maintained a stratified, saline lagoon. The relatively large fish collected in 1988 are from a lagoon population estimated at less than 50 fish and represent the survivors of a shallow, warm, saline summer lagoon.

WADDELL CREEK LAGOON STEELHEAD STANDARD LENGTHS (mm)

1985

```
      16 JUNE                                          14 NOVEMBER
      (n = 273)                                        (n = 321)

 30   X
      X
 40   XXXXXXXXXXXXX
      XXXXXXXXXXXXX
 50   XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 60   XXXXXXXXXXXXXXXXXX
      XXXXXXXXXXXXXXXXXX
 70   XXX
      XXX
 80   X                                                X
      X                                                X
 90   XXXX                                             XX
      XXXX                                             XX
100   XXX                                              XXXXXX
      XXX                                              XXXXXX
110   X                                                XXXXXXXXXXX
      X                                                XXXXXXXXXXX
120   X                                                XXXXXXXXXXXXX
      X                                                XXXXXXXXXXXXX
130   •                                                XXXXXXXXXXXXXXXXXXX
      *                                                XXXXXXXXXXXXXXXXXXX
140   •                                                XXXXXXXXXXXXXXXXXXXXXXXX
      •                                                XXXXXXXXXXXXXXXXXXXXXXXX
150                                                    XXXXXXXXXXXXXXXX
                                                       XXXXXXXXXXXXXXXX
160                                                    XX
                                                       XX
170                                                    X
                                                       X
```

Figure 50. Standard lengths of steelhead from Waddell Creek Lagoon in 1985, showing fast summer growth and conversion of the bimodal sizes of the June population to unimodal sizes by November, due to relatively greater growth by young-of-year fish.

WADDELL CREEK LAGOON STEELHEAD STANDARD LENGTHS (mm)

1986

	8 JUNE (n = 397)	25 JULY (n = 436)	12 OCTOBER (n = 269)
30	XXXXXXX		
	XXXXXXX		
40	XXXXXXXXXXX	*	
	XXXXXXXXXXX	*	
50	XXXXXXXXXXXXXXXXXXXXXXXX	XXXXX	X
	XXXXXXXXXXXXXXXXXXXXXXXX	XXXXX	X
60	XXXXXXXXXXXXXXXXXXX	XXXXXXXXXXX	XX
	XXXXXXXXXXXXXXXXXXX	XXXXXXXXXXX	XX
70	XXXXXX	XXXXXXXXXXXXXXXXXXXXXXXX	XXXXX
	XXXXXX	XXXXXXXXXXXXXXXXXXXXXXXX	XXXXX
80	XX	XXXXXXXXXXXXXXXXXXXXXXXX	XXXXXXXX
	XX	XXXXXXXXXXXXXXXXXXXXXXXX	XXXXXXXX
90	XXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXXXX
	XXXXXX	XXXXXXXXXXXXX	XXXXXXXXXXXXXXX
100	XXXXXXXXXXX	XXXXXX	XXXXXXXXXXXXXXXXX
	XXXXXXXXXXX	XXXXXX	XXXXXXXXXXXXXXXXX
110	XXXXXXXXXXXXX	XXXX	XXXXXXXXXX
	XXXXXXXXXXXXX	XXXX	XXXXXXXXXX
120	XXX	XXXX	XXXXXXX
	XXX	XXXX	XXXXXXX
130	X	XXXXX	XXXXXXXXXXXX
	X	XXXXX	XXXXXXXXXXXX
140		XXX	XXXXXXXXXXXXXXXXX
		XXX	XXXXXXXXXXXXXXXXX
150		*	XXXXXXXXXXX
		*	XXXXXXXXXXX
160			XX
			XX

Figure 51. Standard lengths of steelhead from Waddell Creek Lagoon in 1986, showing retention of bimodal size frequency throughout summer, due to reduced growth of young-of-year fish compared to 1985.

WADDELL CREEK LAGOON STEELHEAD STANDARD LENGTHS (mm)

	1985 14 NOVEMBER (n = 321)	1986 12 OCTOBER (n = 269)	1988 30 OCTOBER (n = 215)
50		X	
		X	
60		XX	
		XX	
70		XXXXX	X
		XXXXX	X
80	X	XXXXXXXX	XXX
	X	XXXXXXXX	XXX
90	XX	XXXXXXXXXXXXXXX	XXXXX
	XX	XXXXXXXXXXXXXXX	XXXXX
100	XXXXXX	XXXXXXXXXXXXXXXXX	XXXXX
	XXXXXX	XXXXXXXXXXXXXXXXX	XXXXX
110	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXX
	XXXXXXXXXXX	XXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXX
120	XXXXXXXXXXXXX	XXXXXXX	XXXXXXXXXXXXXXX
	XXXXXXXXXXXXX	XXXXXXX	XXXXXXXXXXXXXXX
130	XXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXX
	XXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXX
140	XXXXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXX
	XXXXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXX
150	XXXXXXXXXXXXXXXX	XXXXXXXXXXX	XXXXXXXXX
	XXXXXXXXXXXXXXXX	XXXXXXXXXXX	XXXXXXXXX
160	XX	XX	XXXX
	XX	XX	XXXX
170	X		XX
	X		XX

Figure 52. Standard lengths of steelhead from Waddell Creek Lagoon in October - November of 1985, 1986, and 1988, showing large, unimodal fish sizes in 1985 and 1988, when the lagoons coverted to freshwater, and smaller mean sizes and bimodal size frequency in 1986, when late July sandbar breaching resulted in salinity stratification and poor dissolved oxygen conditions.